The Principles of Aeroplane Construction.

With Calculations, Formulæ and 51 Diagrams.

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PREFACE

THIS work is intended to show the principles of the aeroplane as applied to flying machines and to put in as concise a form as possible the theory of the aeroplane, commencing with the elementary laws of mechanics and the inclined plane, and afterwards giving the formulæ for the determination of the principal dimensions of the aeroplane in the simplest form, with numerically worked out calculations on the two systems in use. I have also given a method of analysing the expenditure of energy in the aeroplane in flight. The curves of the aeroplane, its stability, and balance, are referred to. The present-day aeroplane machines are shown. Details of machines exhibited at Olympia, 1910, are given in column form with observations thereon.

I have not attempted to give a theory of stability and balancing, as experimental data are not obtainable from which to estimate the various forces, actions and reactions involved. Little or

no information on these important points can be gathered from the prize-winning flights as reported in the scientific journals, and other sources of information are very scarce. The construction and design of machines is beyond the scope of this little work, for the reason that when the true theory of balancing and stability is apprehended, the design and construction of aeroplane machines will be considerably different from that now prevailing.

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FIRST PRINCIPLES OF AEROPLANES

CHAPTER I

ELEMENTARY MECHANICS AND PHYSICS

THE student of aeroplane machines and flying machines in general may be supposed to have mastered the elementary principles of mechanics, physics, and mathematics.

As we shall deal mathematically in this work only with simple equations, and ordinary arithmetical examples worked out, no extensive mathematical knowledge is necessary. It may, however, be useful to refer to the mechanical and physical sciences briefly, so that the discussion of the subject may be easily understood without reference to other works on these elementary subjects.

In this country we still use the units for

measurement, the foot, the pound, and the second, in our business and workshops. Some attempt the use of the centimetre, the gramme, and the second, but unless these were universally accepted and employed it is perhaps better to adhere to our older units in works for practical men.

The foot and the second give us the units of velocity and acceleration. A velocity equal to 1 is 8 ft. per second.

An acceleration whose measure is 1 is a gain of velocity equal to 1 ft. per second in a second.

In gravitation measure forces are measured by the weights they will support, hence a force which will support 3 lb. = 3.

Forces are also measured by the velocity they generate per second in the unit of mass. A force whose measure is 1 is therefore a force that generates in 1 lb. of mass a velocity of one foot per second in a second.

For example, let a force F generate a velocity of 47 ft. in one second in a body weighing 5 lb.:

We know that the pull of the earth equals the weight; 5 lb. would generate a velocity of 32·2 feet in one second, the force then would be 5 lb. We can therefore find the force F by comparing the quantities of motion produced.

The quantity of motion = MV, wherein M is mass and V the velocity.

Hence $\frac{F}{5} = \frac{MV_1}{mg} = \frac{V_1}{g}$,

V_1 = velocity generated by F,

g = velocity generated by gravitational force,

$\therefore F = \frac{5 \times 47}{32 \cdot 2} = 7 \cdot 3$ lb.

Generally if a force F generate a velocity V in one second in a body weighing W lb., or in other words if V be the acceleration of the body produced by F, and g the acceleration produced by the pull of the earth, we get—

$$\frac{F}{W} = \frac{MV}{mg} = \frac{V}{g} \text{ or } F = \frac{WV}{g} \text{ lb.}$$

But $\frac{W}{g}$ = the mass of the body, therefore the mechanical law shown by this formula is this:

F = mass × acceleration V, or acceleration $= V = \frac{F}{M} \frac{\text{force}}{\text{mass}}$.

The unit of mass is the quantity of matter in a body weighing g lb.

As before stated, a force whose measure is 1 unit is a force which generates in 1 lb. of mass a velocity of 1 foot per second in a second, and the magnitude of this force can be ascertained thus: The weight of a pound acting on the mass of a pound gives the mass a velocity of 32·2 ft. per second in a second, hence the

measure of this force is 32·2. It contains, therefore, 32·2 units of force. Hence the unit of force is $\frac{1}{32 \cdot 2}$ of the weight of a lb.—practically half an ounce.

That is to say, if a pressure of half an ounce were brought to bear on a pound weight continuously for one second, neglecting any friction or resistance, the weight at the end of the second would have acquired a velocity of one ft. per second, or an acceleration = 1.

The force producing acceleration $= \frac{W}{g} f$. With uniform acceleration the final velocity V is $V = ft$, f being the acceleration per second in feet per second per second, and t the time during which the force acts in seconds, s the space moved through in the time $t = s = \frac{V}{2} t = \frac{1}{2} f t^2$.

An aeroplane machine weighing 1000 lb. starts on a level and attains a speed of 30 miles per hour within one minute. What was the mean force of the propulsion T?

$$f = \frac{V}{t} = \frac{\overset{\text{Miles.}}{30} \times \overset{\text{Feet.}}{5280}}{1 \times 60 \times 3600} = \frac{22}{30}.$$

$$T = \frac{Wf}{g} = \frac{1000}{32} \frac{22}{30} = 23 \text{ lb.}$$

Any body accelerated from rest to a final

velocity V per second reacts upon the thrusting or propelling implement with a thrust $= T = \frac{WV}{g}$.

In the aeroplane machine the propeller drives a mass of air astern of weight W, with a velocity V, which has been attained by acceleration. The reaction gives the propelling thrust T.

An aeroplane flying through the air at an angle to its line of flight accelerates the air it meets to a velocity V downward. The weight of air so accelerated = W, the reaction which lifts the machine equals $T = \frac{WV}{g}$.

Note.—Miles per hour $\times \frac{22}{15}$ = feet per second.

A hundred lb. of air coming under the inclined aeroplane in its flight is deflected from a state of rest to a velocity $V = 10$ ft. per second downwards, produces an upward reaction or thrust equal to $T = \frac{100 \times 10}{32 \times 1} = 31$ lb., supporting or lifting the plane against gravity.

This is the whole secret of the aeroplane flying machine. An inclined plane driven through the air, the plane inclined to the "line of flight" deflects a mass of air of weight W downwards with a velocity of acceleration equal to V, giving an action equal to $\frac{WV}{g}$. This action is equal and

opposite to the reaction on the plane, which is thrust UPWARD with a force $= \frac{wv}{g}$.

This is shown in diagram Fig. 1.

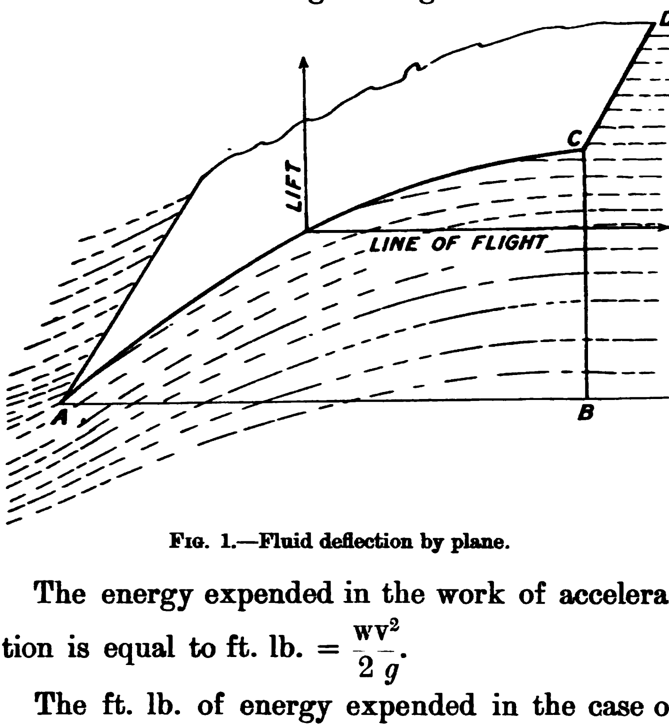

FIG. 1.—Fluid deflection by plane.

The energy expended in the work of acceleration is equal to ft. lb. $= \frac{wv^2}{2g}$.

The ft. lb. of energy expended in the case of the aeroplane machine weighing 1000 lb. starting from rest and running up to 32 feet per second would be—

$$\text{Ft. lb.} = \frac{1000 \times 32 \times 32}{2 \times 32} = 16{,}000 \text{ ft. lb.}$$

A horse-power = 550 ft. lb. per second.

Hence, if the machine were raised to the velocity of 32 feet in one second the horse-power required to do it would be—

$$= \text{HP} = \frac{16{,}000}{550} = 30 \text{ nearly.}$$

But if we gave longer time in which to accelerate the machine up to 32 feet per second (or any other speed) we could do the work with less "horse-power." The work done in ft. lb. would be no less, but being done in longer time less power is required—a weaker power working longer time. Suppose the horse-power was only 16 on the flying machine, then the ft. lb. per second available would be—

$$\text{Ft. lb.} = 550 \times 16 = 8800 \text{ per second.}$$

The number of seconds t this energy would require to act to give the required ft. lb., = 16,000, would therefore be—

$$t = \frac{16{,}000}{8800} = 1{\cdot}81 \text{ seconds.}$$

The space s traversed by the machine in 1·81 seconds t would be equal to (2) $s = t\frac{v}{2} = 1{\cdot}81 \times \frac{32}{2} = 28{\cdot}9$ feet.

In some aeroplane machines, notably that of the famous Wright brothers, a falling weight was

used to give force sufficient to accelerate the machine up to a starting speed, along with the engine-power, in a reasonable distance.

The machine takes considerably more energy per second to accelerate it up to flying speed than it does to keep it flying at a uniform speed. When flying at a uniform forward speed the work done is constant in deflecting air downwards under the planes and in friction against the air, but in starting up we have in addition to these resistances the energy absorbed by the acceleration equal to $\frac{wv^2}{2g}$.

The machine would fly with 16 horse-power, but to raise it to flying speed—60 feet per second —it required, as it weighed 1000 lb., ft. lb. =

$$\text{Ft. lb. } \frac{1000 \times 60^2}{2 \times 32} = 56{,}250.$$

The available ft. lb. per second in the engine was 16 × 550 = 8800, which we find would start the machine in—

$$t = \frac{56{,}250}{8800} = 6{\cdot}4 \text{ seconds,}$$

and in a run of a distance—

$$s = t\,\frac{v}{2} = 6{\cdot}4 \times \frac{60}{2} = 192 \text{ feet.}$$

In order to reduce the space to be traversed and the time taken to start up, either the engine

would require to be enlarged or to use an extraneous force at the start; the Wright brothers chose the latter alternative.

They arranged a weight of 1500 lb., which could be wound up to 20 feet height and attached to a cord hooked on to the aeroplane; in falling the weight pulled the aeroplane, and in doing so gave energy equal to h, the height fallen multiplied by the weight $= w \times h = 20 \times 1500 = 30{,}000$ ft. lb.; so that $56{,}250 - 30{,}000 = 26{,}250$ ft. lb. were left to the engine to supply, which it would do in $\frac{26{,}250}{8800} = 3$ seconds; and the distance run in 3 seconds would then be—

$$s = t\frac{v}{2} = 3 \times \frac{60}{2} = 90 \text{ feet.}$$

This device therefore enabled flying to be accomplished by a small-power engine, but as a falling weight suitably arranged cannot be found everywhere a flying machine might land it was abandoned, and aeroplane machines now carry engines of sufficient power to accelerate them from rest up to flying speeds on any fairly smooth surface. But they cannot rise of their own power from a forest of trees or from a rough ploughed field.

THE PARALLELOGRAM OF FORCES.

A force is any cause which moves or tends to move matter. Suppose a particle, Fig. 2, to be acted upon by two forces P Q, their direction being in the direction of the lines PA and QA and their magnitude proportional to the length of the lines. Unless the forces are equal and opposite in the same straight line the particle will be moved in some direction with a definite force. But one

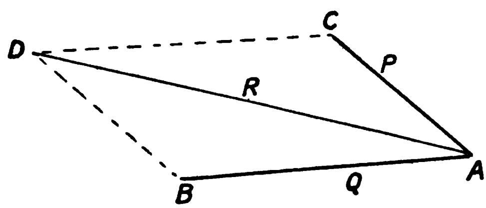

FIG. 2.—Parallelogram of forces.

single force R can move a particle in a definite direction with a given velocity. Therefore there is some single force R intermediate between P and Q which produces the same effect as P and Q combined.

This single force R is called the resultant, and P and Q are the components of R. The process of finding two forces equal to a single force R is called the resolution of the force. And the process of

finding R from the two forces P and Q is called the composition of the forces.

The principle of the parallelogram of forces is thus stated: If two straight lines drawn from a point represent in magnitude and direction any two forces acting on that point, and if the parallelogram on these lines be completed, the resultant of the two forces will be represented in direction and magnitude by that diagonal of the parallelogram which passes through the point where the forces act.

Thus if a force be represented by CA, and another by BA, Fig. 2, completing the parallelogram A B C D and joining AD, gives the diagonal passing through the point where the forces act, and the direction and length of the resultant force are the direction and magnitude of the resulting force.

Velocities are compounded in the same way. Thus if a plane is inclined to a blast of air, or is moved against the air, and inclined by an angle a to the line of flight, it encounters a pressure, P which acts in a direction d normal to the plane; this pressure is proportional to $d = V^2A$, Sin a.

This force can be resolved into two forces, T a lifting force, and D a horizontal force proportional to $D = V^2A$, $\text{Sin}^2\, a$, and T, the lift, is proportional to $T = V^2A$, Sin a, Cos a.

v is velocity of plane in feet per second, and A its area in square feet.

The idea of work is connected with force and motion; force produces motion when work is done.

An aeroplane when in full horizontal flight has no upward motion, although a force equal to its own weight is acting upwards upon it. We might conclude that while there was a force acting where there is no motion produced by it, there is, therefore, no work being done. This, however, is not true in the case where the force acting is due to the reaction of the momentum of a body or fluid, for although the force produces no upward motion of the aeroplane, the fluid producing the force is in motion, and the work done is proportional to $\frac{wv^2}{2g}$ applied to the fluids weight and acceleration.

Similarly a man supporting a weight might be said to perform no work, as there is no motion of the weight, but the support given by the man is due to molecular or atomic motions in his muscles, and if we could measure these they would give a force equal and opposite to the weight, and due to $\frac{wv^2}{2g}$, v being the velocity of the muscular atomic velocities.

An electro-magnet is a similar case; an electro-

magnet will support a large weight, seemingly doing no work, for the weight is not moving, but work is being done proportional to the electric current flowing in the magnet coils multiplied by the electric pressure.

CHAPTER II

PRINCIPLES OF INCLINED PLANES

LET Fig. 3 be an inclined plane in which AB is the plane, AC the base, and BC the perpendicular; the three sides form what may be called the "triangle of the plane."

Let P represent the pull, or push, moving a body F up the plane, the direction of the force P being parallel to the base of the triangle. The vertical arrow represents W the weight of the body. And R normal to the plane is the resultant of the two forces P and W.

From C draw a line parallel to R, cutting AB in c, and from c draw a line parallel to the base, cutting BC at *b*.

Then it can be shown that $\frac{\text{P}}{\text{W}} = \frac{bc}{bc} = \frac{\text{BC}}{\text{AC}} = \frac{\text{height of perpendicular}}{\text{base}}$.

The weight raised = W.

If W = 6 and P is found to be = 1, then—

$$\frac{\text{P}}{\text{W}} = \frac{1}{6} \therefore \frac{\text{BC}}{\text{AC}} = \frac{1}{6}.$$

The ratio of BC to AC is the ratio of the force P to the weight W.

If there were no friction on the inclined plane when P is proportional to BC and W to AC, the forces P and W would be in equilibrium, and the body would be balanced between the two. When motion occurs work is done. If the body F moves horizontally from A to C while rising from C to B

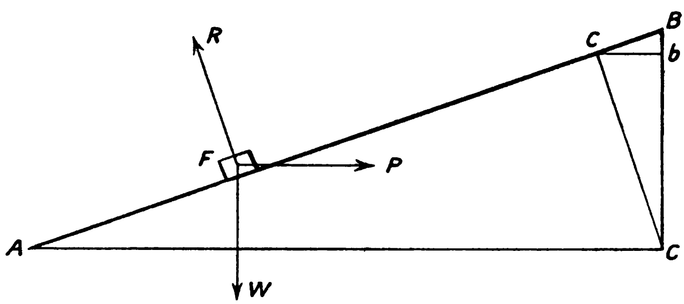

FIG. 3.—Inclined plane.

in 60 seconds, and AC = 60 ft. and CB = 10 ft., V, the horizontal velocity, is 60 ft. per second, while V_1, the vertical velocity, is 10 ft. per second.

If W = 1 lb. the work done to raise 1 lb. 10 ft. per second = 10 ft. lb. The pull P travels in the same time 60 ft., and as the ft. lb. in the pull must equal the ft. lb. in the lift,

$$P = \frac{10 \text{ ft. lb. per sec.}}{60 \text{ ft. per sec.}} = \tfrac{1}{6}\text{th lb.}$$

The inclined plane in this case is fixed and the body F movable under the force P.

But the plane may be moving, that is to say pushed under the body F, like a wedge, in which case the body will be raised while the plane moves.

The same effects occur if $\frac{BC}{AC} = \frac{1}{6}$, then $\frac{P}{W} = \frac{1}{6}$ as before. They will balance when no motion occurs, but adding force to P in order to do the work of lifting the weight, work will be done proportional to the weight lifted, multiplied by the height lifted per second.

In Fig. 3, if AC is 6 ft. and BC 1 ft., for every 6 ft. travelled by the wedge the weight will be lifted 1 ft., and if the weight is 1 lb. the work done will be 1 ft. lb. for every 6 ft. of travel of the plane. Then in a 60 ft. length travelled in one second, the work done would be 10 ft. lb. per second.

The most important point to note in this case where the plane moves, and the weight is thrown up only, is that the plane moves horizontally to lift the weight vertically. When the forces just balance, that is, when $\frac{P}{W} = \frac{BC}{AC}$, there is no motion.

But if the push is increased to perform the work of lifting the weight, the downward thrust

on the plane is increased; it is no longer only equal to W, it is now equal to $\frac{WV}{g}$, V being the velocity with which it is being lifted in feet per second, and $g = 32{\cdot}2$.

Taking the above case, in which an inclined plane moving under a body F of weight W lifts it 1 ft. while moving the length of its base = 6 ft., and moving at the rate of 60 ft. per second, V = 10 ft. per second evidently, hence the downward pressure of the body F will be under these conditions $= T = \frac{WV}{g} = \frac{1 \times 10}{32} =$ 5 oz. more than its weight.

This 5 oz. additional downward pressure is due to the reaction of the weight to the acceleration of its motion.

Many students not quite familiar with elementary dynamics and the mechanics of fluids and inclined planes may have a difficulty in comprehending the basis of the theory of the aeroplane, upon which the formulæ for the calculation of its principal dimensions are founded.

The following is an explanation designed to assist in comprehending the subject clearly. It is based upon the principles of the inclined plane, and the reaction of a fluid accelerated by inclined plane action from a state of rest to a velocity V in a downward or upward direction.

The lift or reaction of the air upon the plane is found from the weight W of air accelerated per second in lb. by deflection in a downward direction at a rate in feet per second represented by a velocity V. The lift is then ascertained by the momentum formula $T = \frac{WV}{g}$.

And the weight of air necessary to obtain a given thrust is equal to $W = \frac{T \times g}{V}$ . . . . (1)

The difficulty seems to be to comprehend how weight of air per second equal to W is found and how V, its acceleration, is ascertained.

To anyone acquainted with the mechanics of the inclined plane there should be no difficulty; taken with the fundamental law of action and reaction being opposite and equal the result should be clear.

The inclined plane, however, is usually treated as dealing with a solid weight hauled up, or a body sliding down, and not often as lifting a fluid. It may assist in understanding the elementary problem if we first consider the case of an inclined plane acting on water, and from that proceed to the consideration of its action in air.

Imagine an inclined plane arranged as a scoop driven at a velocity, S, over the water, as in Figs. 4 and 5.

Here the depth of the water lifted is proportional to BC, and its breadth BD, the span of

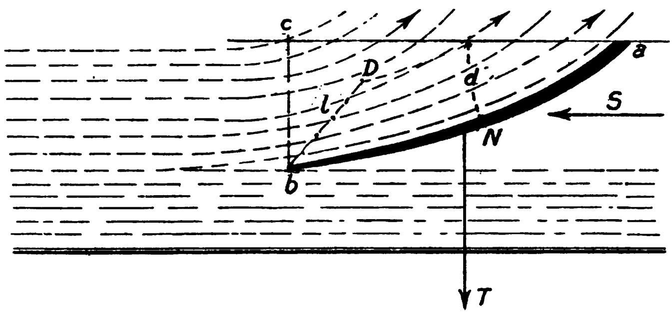

FIG. 4.—Fluid lifting plane.

the plane. BC is the perpendicular of the triangle of which the plane AB is the hypotenuse and AC is the base.

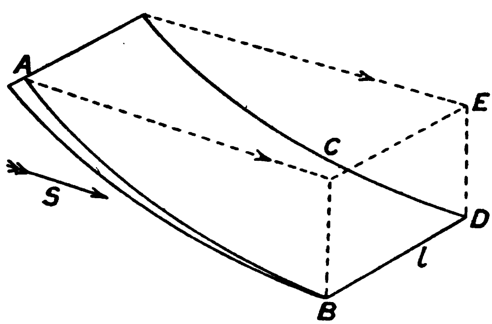

FIG. 5.—Scoop.

The length of BC will depend upon the angle A with any given length of base AC.

Suppose now this plane were driven ahead at 60 feet per second, and AC = 5 feet, while BC = 0·5 feet, it will be clear that while the plane travels the length of its own base it will lift the water during that time the height of BC. At 60 feet per second the plane would travel the length of its own base, which is 5 feet in $\frac{60}{5} = \frac{1}{12}$th of a second.

Hence the water will be lifted 0·5 feet in $\frac{1}{12}$th second.

Now this is the important point; it is the rate of lifting which is important, for it is an acceleration of the water from rest to an upward velocity of 0·5 feet in $\frac{1}{12}$th second.

A rate of lifting of 0·5 feet per $\frac{1}{12}$th second is equal to 6 feet per second = $0{\cdot}5 \times 12$, hence the rate at which the fluid is accelerated from a state of rest to a velocity of 6 feet per second is found in this case from the known data given as

s = speed of plane ahead.

v = acceleration of fluid from rest (to a speed of 6 feet per second in this case).

BC, perpendicular of triangle of plane.

AC, base of triangle of plane.

To find the value of v it will be seen from the above that we divided s by the base length AC, and we multiplied by BC.

Hence $V = \frac{S \times BC}{AC} = \frac{60 \times 0{\cdot}5}{5} = 6$ feet per second per second = acceleration V.

Now for W, the weight of air accelerated per second, supposing the fluid to be air.

A, the sectional area of the fluid lifted perpendicularly by the plane, is clearly equal to the span BD of the plane multiplied by its ahead velocity S per second, for that will give the superficial area of the slice of water acted upon in one second and thrown upwards.

The whole mass accelerated to V is equal to $l \times S \times BC \times V$, wherein l = span of plane equal to BD or $l \times S = A : \therefore A \times BC \times V$ = mass of air in cubic feet, if dimensions are in feet, and the mass per second accelerated will therefore be in cubic feet—

$$\text{Cub. ft.} = A \times BC \times V,$$

for it is accelerated at the rate of V per second at any instant in the path of the plane.

The weight of air W accelerated per second is therefore, taking one cubit foot to weigh 0·08 lb.,

$$W = A, BC, V, 0{\cdot}08 \quad . \quad . \quad (2)$$

and its reaction or lift T—

$$T = \frac{(A, BC, V, 0{\cdot}08)\ V}{32} \quad . \quad . \quad (3)$$

The expression in brackets is W. Cancelling down,

$$T = A, BC, V^2, {\cdot}0025 \quad . \quad . \quad (4)$$

Now, in this system it may be asked why BC, the perpendicular of the triangle of the plane, is a factor in the determination of W, since the amount of fluid in a stream is proportional simply to A × V. The reason is that in the aeroplane problem we are not dealing with a stream flowing at a steady velocity V.

We are dealing with the case of accelerating a mass of fluid from a state of rest to a certain velocity V. And in estimating the mass we take the whole mass coming under the four corners of the plane, and the rate at which it must be accelerated to flow up the plane and clear it. The mass of fluid is, on this view, equal to BC × A, A being the area swept by the plane in a second.

As this mass is accelerated to V = 6 ft. per second, we multiply it by V in order to bring it into mass accelerated per second; and the mass accelerated per second, or—

$$\frac{\text{“weight accelerated per second} \times \text{the acceleration”}}{\text{gravity acceleration}}$$

equals reaction in pounds weight.

It may be said that the plane deflects far more air than that which comes immediately through BC, for the plane in an aeroplane is submerged, and any disturbance in one locality in the air must have effects all around it.

That may be so, but such a theory could not

give any determinate data. We have to take the facts of the case, and these are that an inclined plane accelerates the fluid which comes in immediate contact with it, and through an area which is proportional to BC, multiplied by the span BD, Fig. 5. And calculating upon that basis the results agree remarkably well with the actual results with planes in work.

How far the effect of the action on the air extends, or where it may be felt in its motion, is another problem which does not concern us here.

The effect is the same in air as in water, only that the aeroplane is submerged. And then there is the effect on the back of the plane.

The air surrounds the aeroplane on all sides, with a pressure of about a ton per square foot. The screw propeller blades of an aeroplane may press upon the air with a pressure of about 40 lb. per square foot of blade area, but 40 lb. is a very small percentage of 2216 lb. An aeroplane wing may press upon the air with a pressure of 5 lb. per square foot, a still smaller percentage of 2216 lb., hence practically the compression of the air is negligible in either case. And it will be admitted that it would be difficult to form a partial vacuum in an open atmosphere of air under 2216 lb. pressure in all directions per square foot.

The only upward suction possible on the back of the aeroplane would be that proportional to a difference of pressure producing a velocity equal to v in our formulæ, say 6 ft. per second in the case taken.

If x is the difference of pressure in inches of water then $v = 64{\cdot}4\sqrt{x}$, and $x = \left(\frac{v}{64{\cdot}4}\right)^2$, hence if $v = 6$ ft. per second $x = \left(\frac{6}{64{\cdot}4}\right)^2 = 0{\cdot}0082$ inch of water column nearly. An inch of water has a pressure per square foot roughly of about 5 lb., hence the suction would be equal to $0{\cdot}0082 \times 5 = 0{\cdot}041$ lb. per square foot; acting vertically, a negligable amount of lift due to the fact that the air moves with such enormous velocity under a small difference of pressure and therefore follows up the plane under this small pressure difference.

But the plane, besides sucking the air down vertically, sucks it horizontally after it with a velocity proportional to its forward speed—in this case 60 feet per second.

x in this direction will equal—

$$x = \left(\frac{v}{64{\cdot}4}\right)^2 = \left(\frac{60}{64{\cdot}4}\right)^2,$$

equal to 0·84 inches water, and giving a back pull of $5 \times 0{\cdot}84 = 4{\cdot}2$ lb. on area BD × BC (Fig. 5).

Referring to Fig. 6, the parallelogram on the back of the plane represents the case: the downward velocity is represented by the vertical short line, bc = 6 feet per second; the forward velocity, 60 feet per second, is represented by the horizontal line, ab; the resultant velocity of the air following the plane is shown by diagonal bd.

But it is pressures we must deal with; hence

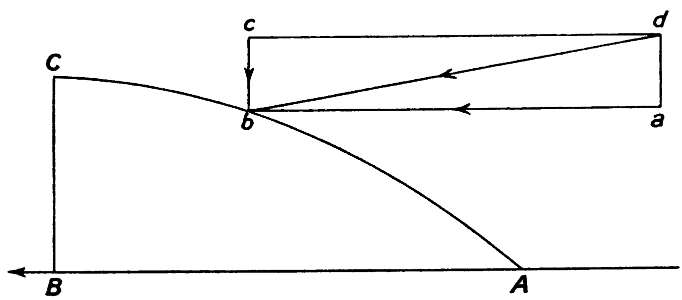

Fig. 6.—Suction and drag on back of plane.

we find from formulæ $x = \left(\frac{\text{V}}{64{\cdot}4}\right)^2$, the pressures due to these velocities.

The upward pull is *proportional* to BA × bc (Fig. 6). The back pull is proportional to BC × ba.

BA = 5 feet, BC 0·5 feet.

The proportion of the upward pull to the backward pull is therefore—

5 × ·041 = ·205.

$0{\cdot}5 \times {\cdot}84 = 4{\cdot}2$.

For these reasons the suction on the back of the plane may in practice be entirely neglected; if anything, it is a drawback. And we count only upon the reaction of the air positively deflected downwards by the under-surface of the plane.

The primary fact that the surrounding air is

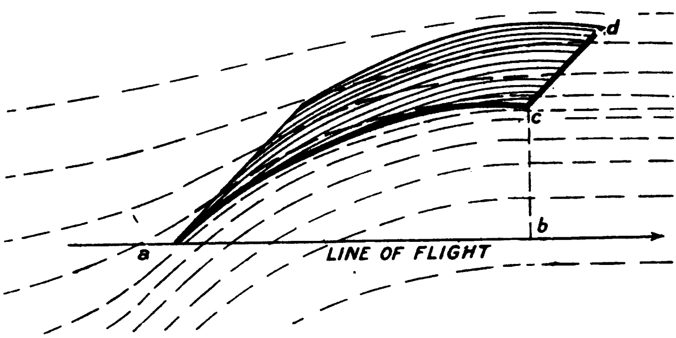

FIG. 7.—Sheet plane.

under 2216 lb. pressure per square foot alone would show that there could be very little to be gained from any partial vacuum effects at aeroplane velocities.

The ratio of the upward lift to the backward pull due to suction on the back of the plane can be altered by giving the back of the plane a different curve from that of the front as shown in Figs. 19 and 20.

A plane shaped like that shows a greater lifting effect and less back pull in a current of air than a plane of thin sheet metal throughout, as in Fig. 7.

But testing for lift by placing a plane or planes in a current of air gives a result of very little, if any, practical value. A blunt-nosed plane like Fig. 20 may give a higher lift in a current of air, but it may also oppose a higher resistance to propulsion ahead.

The only reliable results of tests upon aeroplanes for lift, and head resistance, or efficiency, are those obtained by planes actually driven through still air at a known velocity, and with all the data accurately given. It is a difficult test to make, but that does not render it in any degree less necessary if real knowledge is to be obtained from tests.

CHAPTER III

AIR AND ITS PROPERTIES

At sea level the pressure of the atmosphere has a mean value of 14·17 lb. per square inch or 2116 lb. per square foot, and is due to a column of air of mean density equal to that at sea level and five and a half miles high, or 27,801 ft. at ordinary temperature.

The water barometer has a column 33 ft. high; a pressure of 1 lb. per square inch is measured by a column of air of uniform density of 1891 ft., or mercury 2·04 in., or of water 2·3 ft. high; 1 lb. per square foot is measured by a column of air 13·13 ft. high, or of water 0·1925 in.

For our examples we take the weight of a cubic foot of air as 0·08 lb. The exact volume and weight at different temperatures is given in Table I.

The pressure of the atmosphere being 2116 lb. per square foot near the earth, and the pressure of an aeroplane in full flight with full load does not

TABLE I.—*Volume and Weight of Air at Various Temperatures.*

Deg. Fah.	Volume at atmospheric pressure.		Density or weight in lb. per cubic feet at atmospheric pressure.	Pressure at constant volume.	
	Cubic feet in 1 lb.	Comparative volume.		Pounds per square in.	Comparative pressure 62° Fah. = 1.
0	11·583	·881	·08633	12·96	·881
32	12·387	·943	·08072	13·86	·943
40	12·586	·958	·079439	14·08	·958
50	12·840	·977	·077884	14·36	·977
62	13·141	1·000	·076097	14·70	1·000
70	13·342	1·015	·074950	14·92	1·015
80	13·593	1·034	·073565	15·21	1·034
90	13·845	1·054	·072230	15·49	1·054
100	14·096	1·073	·070942	15·77	1·073
110	14·344	1·092	·069721	16·05	1·092
120	14·592	1·111	·068500	16·33	1·111
130	14·846	1·130	·067361	16·61	1·130
140	15·100	1·149	·066221	16·89	1·149
150	15·351	1·168	·065155	17·19	1·168
160	15·603	1·187	·064088	17·50	1·187
170	15·854	1·206	·063089	17·76	1·206
180	16·106	1·226	·062090	18·02	1·226
200	16·606	1·264	·060210	18·58	1·264
210	16·860	1·283	·059313	18·86	1·283
212	16·910	1·287	·059135	18·92	1·287

exceed 5 lb. per square foot, it will be understood that the compression of the air by the aeroplane will be as $\frac{2116}{2116 + 5}$, and may be neglected.

If h represents the height of a column of water in inches, due to a difference of pressure in the

air, then the velocity with which the air would rush in to restore the pressure is equal to $64\sqrt{h}$.

A barograph or statoscope indicates the height above the sea level; the common aneroid barometer is so used, and is available for measuring heights up to 10,000 ft.

Much more sensitive instruments are made, which indicate slight changes in elevation, such

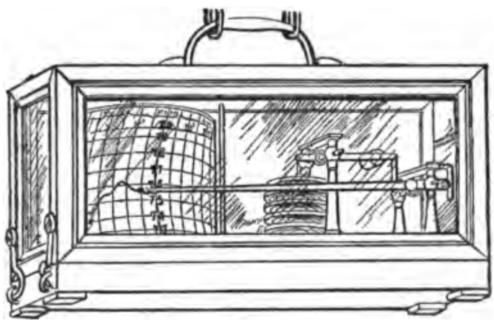

FIG. 7A.—Barograph.

as we wish to observe when in the air at great heights. It is difficult to estimate whether the balloon or flying machine is rising or falling. Statoscopes are used to indicate the rise or fall.

The statoscope consists of a series of very sensitive boxes (somewhat like the vacuum chambers of aneroids), contained in a hermetically sealed reservoir, which is placed in a box thickly surrounded by wool so as to prevent the disturbing

influence of change of temperature during any experiments. It is, in fact, an air barometer from which the normal pressure (15 lb. per square inch) of the atmosphere is excluded. With this instrument a change of $\frac{1}{1000}$th of an inch of the barometer is represented by a motion of the needle of 0·025 in., or 25 times as great; consequently, if the instrument is raised 3 ft. the indicating pen traverses an angular space of nearly a tenth of an inch.

CHAPTER IV

PRINCIPLES OF THE AEROPLANE

THE aeroplane deals with a fluid air, but the reaction due to its acceleration can be calculated in the same way as for water on inclined plane principles.

Figs. 8–10 illustrate an aeroplane scooping a fluid, air or water. The plane is curved for this purpose in order that the fluid may be accelerated downwards, without disturbance and gradually. The triangle of the plane is A C B. If AB = 6 ft. and BC = 1 ft., for every 6 ft. the plane travels horizontally the fluid will be thrown downwards 1 ft., or at the *rate* of 10 ft. per second if the plane had a forward speed of 60 ft. per second, for the plane would move through 6 ft. in $\frac{1}{10}$th of a second; this rate or velocity rate given to the fluid is represented by V and the forward horizontal speed is represented by S.

$$V \text{ is therefore clearly equal to } S\,\frac{bc}{Ab} \quad . \quad . \quad (5)$$

Hence the sectional area of the air upon which

the velocity V is impressed is equal to the area swept by the aeroplane in one second, and this area is equal to l, the span of the plane BD in Fig. 5, multiplied by the speed of the plane S—

$$A = lS$$

$$\text{and hence } l = \frac{A}{S} \quad . \quad . \quad . \quad (6)$$

A can also be found by—

$$A = \frac{W}{BC \times V \times \cdot 08} \quad . \quad . \quad (7)$$

The important value to find is the reaction on the plane driving or pushing it down in Figs. 4 and 5 (up in an aeroplane), and this is equal to $\frac{WV}{g}$, in which W is the weight of air upon which the plane impresses velocity V and $g = 32$. The cubic feet of air acted upon is equal to—

$$Q = \text{cubic feet} = A.V.BC. \quad . \quad . \quad (8)$$

And as the air weighs 0·08 lb. per cubic foot the weight $W = 0{\cdot}08 \times A \times V$.

$$\therefore T, \text{ the reaction thrust, } = \frac{0{\cdot}08 \times A \times V \times V}{32},$$

$$\text{or } T = AV^2 \times 0025 \times BC \quad . \quad . \quad . \quad . \quad (9)$$

Referring to Fig. 8, the triangle A C B is called the triangle of the plane, the ratio $\frac{BC}{AB}$ is called the ratio of the plane and is equal to $\frac{V}{S}$. Whatever

may be the actual dimensions of the triangle of the plane BC, AC, CA, Fig. 8, or *fe*, *ae*, *fa*, if the forward speed is the same and the ratio the same, V is the same:

$$V = S \frac{BC}{AB} = V = S \frac{fe}{ae} \quad . \quad . \quad (10)$$

V is independent of the span of the plane or of the size of the plane, depending solely on the speed S and the ratio of the plane.

But in actual machines the ratio of the plane

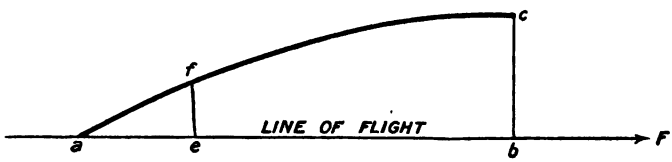

FIG. 8.—Triangle of the aeroplane.

can be varied in flight. In Fig. 8, if the plane AC were moving with its base parallel to the line of flight, the ratio is $\frac{bc}{ab}$.

But by means of elevators or tails the aviator can incline the plane up or down, increasing the angle of the plane to the line of flight or *vice versâ*, as shown in Figs. 9 and 10. In Fig. 10 the base of the triangle of the plane has been tilted up to an angle A with the line of flight, and the ratio of the plane is now $\frac{b_1 c}{Ab_1}$.

In Fig. 9 the base of the triangle of the plane has been depressed, and $\frac{cb_1}{ab_1}$ is now the ratio.

For starting up a machine the plane on wheels is tilted up as in Fig. 10 to give high ratio.

FIG. 9.—Plane tilted down.

In calculations to be made the ratio of the plane is that given in Fig. 8, and is that ratio at which the plane flies straight ahead at the given speed

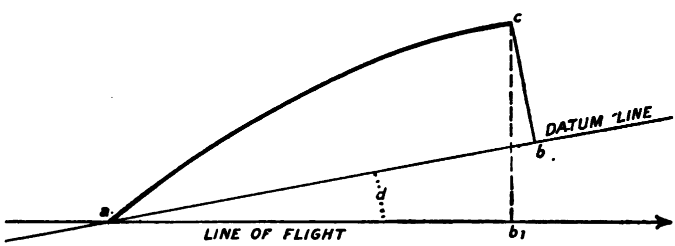

FIG. 10.—Plane tilted up to line of flight.

s, and with the other factors as assumed in the data.

In flight, owing to varying winds and air currents, the aviator changes the ratio to suit the circumstances, hence the calculated ratio should

be a mean ratio, and a good mean ratio is $\frac{\text{BC}}{ab} = \frac{1}{6}$.
We shall see that a plane with a small ratio, say $\frac{1}{12}$ or $\frac{1}{14}$, requires to have a large wing area, and *vice-versâ*, a machine with small wing area requires a high ratio, $\frac{1}{5}$ or $\frac{1}{4}$, but whatever the wing area a mean ratio should be chosen for the calculations.

As to the actual length in feet of the base of the triangle of the plane, in practice it has been used from 9 in. to 8 ft. 6 in. For monoplanes perhaps 7 ft. is a maximum for machines as presently designed, and for biplanes 6 ft. Knowing the length of the base Ab, the length of bC can be found if we have chosen the ratio.

If the ratio is $\frac{1}{6}$ and Ab 7 ft., then $b\text{C} = \text{A}b \times \frac{1}{6}$

$$= 7 \times \frac{1}{6} = 1 \cdot 1\dot{6}\dot{6} \text{ ft.}$$

So far we have dealt with that most important figure, the triangle of the aeroplane, and also with the ratio of the plane, its span, its speed, and the velocity of the air deflected by it.

We can now proceed to show how the principal dimensions may be calculated for an aeroplane to fulfil a given specification.

Assuming the data given or specified to be—

M = total weight, all on, to be carried by the machine, 800 lb. S, the forward speed in still air, in normal flight = 60 ft. sec., V = 10 ft. per second. This factor V is chosen as a mean value; from experience it seems that a higher value of V entails considerable waste of power, while a lower value means a large wing area.

If a small machine is required V may be taken at 12 or even 14 ft. per second, and in large-winged machines as low as 7 ft. per second.

By the principles of mechanics the energy or work expended in producing the lift by the reaction of a weight of air W, given a velocity in feet per second V, is proportional to WV^2; hence it is more economical of power to obtain the lift by great weight of air and a small velocity of deflection V, so that machines with large area of wings are more economical of power than those with small wing area.

But there is a limit to the size of the wings, both at the minimum and maximum. Enlarging the area adds weight, so that a limit is reached where the saving in power is a maximum, when the further addition of area raises the weight beyond the power. In practical machines, as at present constructed, the weight carried per square foot of wing area ranges from 2·5 to 4 lb., with speeds ahead from 35 to 50 miles per hour. Hitherto

aeroplane machines have been built only for sporting and demonstration purposes, carrying only one, or, at a pinch, two men, and for flights of little more than two hours. For any practical purposes machines to accommodate more men and more fuel will require to be larger, for the lifting reaction of a cubic foot of air acted upon by the wings is a known quantity depending upon the ratio $\frac{BC}{AC}$ and the ahead speed S; the ratio cannot be increased without increasing the head resistance to propulsion, neither can S be increased much, for it gives a resistance proportional to the square of S, so that greater carrying power must be obtained by increasing the wing area or by employing multiplanes.

Fig. 11 is a view of a monoplane machine in which the main planes are all in one plane. It is obvious that from constructional considerations a large area of wing surface can be obtained by wings of wide dimensions only. AC must be long, for the length, L, is limited, and if made long will give a weak structure. In these machines the angle of the plane is made large, BC great, so that the ratio $\frac{BC}{AC}$ is great $= \frac{1}{4}$ or $\frac{1}{5}$ in normal flight.

With a biplane construction, shown in Fig. 12, a great wing area can be employed with a strong

construction and a moderate ratio, the two planes being bound together by struts and ties.

In biplane machines the two planes are fixed

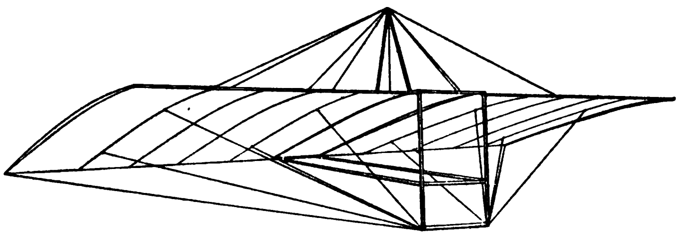

Fig. 11.—Monoplane.

apart by a distance equal to AC. When planes are ranged closer together they interfere with the

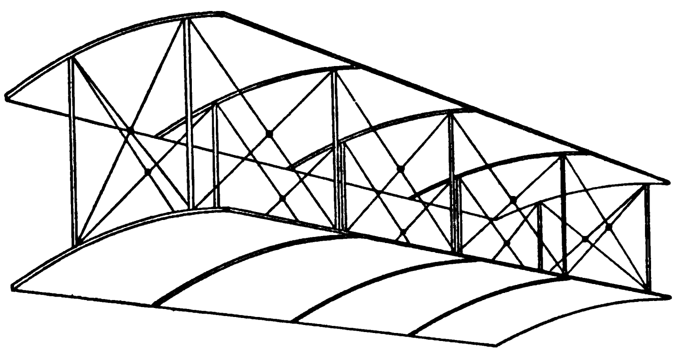

Fig. 12.—Biplane.

air currents of each other and their efficiency is reduced.

In every case, however, the function of the main planes is the same, that is, by deflecting a mass

of air of weight W with a velocity V downwards to obtain an upward reaction lifting the planes, as already explained in the inclined plane principles.

The designer, being given the desired speed and the weight to be carried, may be instructed to produce a design for a machine, instead of fixing upon a value of V, he may fix upon a value of the ratio of the plane and the length of the base of the triangle of the plane, and proceed from that data.

Like other engineering problems some factor or factors must be decided by the designer's judgment and experience.

In the case of the aeroplane design he has given—

M = total weight lbs.

S = speed in feet per second.

V = velocity of air deflected, which must be chosen to suit the conditions under which the machine is to fly.

Or, given M and S, he may be left to choose $\frac{BC}{AB}$, the ratio, and AB, the length of the base of the triangle of the plane, in which case he can find $V = S \times \frac{BC}{AB}$. If $\frac{BC}{AB}$ is to be chosen, it may be, for instance, $\frac{BC}{AB} = \frac{1}{6}$.

Hence in either case we can find V to begin with.

The lift requires to be equal to the weight M, and therefore the upward thrust T is required to be equal to M in pounds. $T = \frac{WV}{g}$ $\therefore$ $W = \frac{T \times g}{V}$, so that we can at once find the weight of air required to be deflected.

In this case M = 800 lb. = T, and if V is found or taken to be 10 ft. per second and BC = 1—

$$W = \frac{800 \times 32}{10} = 2560 \text{ lb. per second.}$$

Q, the cubic feet of this weight of air, will be—

$$Q = \frac{2560}{0 \cdot 08} = 32{,}000.$$

Cubic feet per second divided by V. BC will give the area swept $= A = \frac{32{,}000}{10 \times 1} = 3200$ sq. ft., and as l the span $= \frac{A}{S} =$ the span will be—

$$l = \frac{3200}{60} = 54 \text{ ft. nearly.}$$

A rather long span for a monoplane, but would make a biplane of 27 ft. span.

Take another case, where V is not chosen, but the designer is to make a monoplane of small size. He chooses *ab* long, say 7 ft., and the ratio large, say $\frac{1}{5}$, then *bc* will be $\frac{7}{5} = 1 \cdot 4$ ft.

M = 800, S = 60 as before.

Then—

$$\text{V by (10)} = \frac{\text{S BC}}{\text{AB}} = 60 \times \frac{1}{5} = 12 \text{ ft. per second;}$$

$$\text{W by (1)} = \frac{\text{T} \times g}{\text{V}} = \frac{800 \times 32}{12} = 2134 \text{ lb. of air;}$$

$$\text{A by (7)} = \frac{\text{W}}{\text{V BC} \cdot 08} = \frac{2134}{12 \times 1{\cdot}4 \times 0{\cdot}08} = 1600 \text{ sq. ft.;}$$

$$l \text{ by (6)} = \frac{\text{A}}{\text{S}} = \frac{1600}{60} = 27 \text{ ft.}$$

The wings would then in this case be 7 × 27 = 189 sq. ft. In the first case the designer chose 6 ft. for the length of base from experience, and as he has V and S given the ratio is found by $\frac{\text{V}}{\text{S}} = \frac{10}{60} = \frac{1}{6}$.

$$\text{BC} = \frac{6}{6} = 1 \text{ ft.}$$

The wings would have an area of 6 × 54 = 324 sq. ft.

From experience he would also know that 189 sq. ft. of wing area is an extremely small area, and would entail a considerably greater power, and he would make *bc* smaller or the ratio smaller, for in practice about 5 lb. per square foot of area is the limit of the lift.

Take another example in which the plane and its principal dimensions are given:

A plane is 32 ft. span, AC, the base of the triangle

of the plane, is 6 ft. 6 in., the ratio is 1 to 5; what weight will it lift at a speed of 40 ft. per second?

Ans.—BC will equal $\frac{6 \cdot 6}{5} = 1 \cdot 32$ ft.

V will be equal to—

$$S \times \frac{1}{5} = 40 \times \frac{1}{5} = 8 \text{ ft.}$$

$A = l \times S$, and $l = 32$, and $S = 40$, $\therefore A =$ 1280 sq. ft.

$T = BC\ AV^2\ 0025 = 266$ lb.

Thus two planes in a biplane of this size would lift 532 lb. at a speed of 40 ft. per second ahead.

To obtain a greater lift the ratio must be increased, or the base of the triangle increased, or the span increased.

It will be evident that if AB had been chosen of a shorter length and still retaining the same ratio of the triangle of the plane, $= \frac{1}{5}$, the length of the spans would be greater.

If we take AB the base of the triangle of the plane equal to 2 ft. 11 in. = 35 in., then BC will be $\frac{35 \times 1}{5} = 7$ in. $= 0 \cdot 583$ ft.

V by (10) $= \frac{S \times BC}{AB} = 60 \times \frac{1}{5} = 12$ ft. per second, as before;

W by (1) $= \frac{800 \times 32}{12} = 2134$ lb., as before;

$$\text{A by (7)} = \frac{2134}{12 \times 0{\cdot}58 \times 0{\cdot}08} = 4000 \text{ sq. ft.}$$

nearly, much greater than before; and l will now be $= \frac{4000}{60} = 66$ ft., showing how the same lift at the same ahead speed is obtained with a different base length and keeping to the same ratio of $\frac{\text{BC}}{\text{AB}}$.

As another example to show how we may alter the triangle of the plane and still get same lift at same forward speed, 800, and 60, respectively as T and S, suppose AB = 6·6 ft. and BC is made 0·6 ft., then the ratio will be $\frac{6{\cdot}6}{0{\cdot}6} = \frac{1}{11}$, and then—

$$\text{V} = (10) = \frac{60 \times 1}{11} = 5{\cdot}45 \text{ ft. per second;}$$

$$\text{W} = (1) = \frac{800 \times 32}{5{\cdot}45} = 4680 \text{ lb. of air;}$$

$$\text{A} = (7) = \frac{4680}{5{\cdot}45 \times 0{\cdot}6 \times 0{\cdot}08} = 18{,}000 \text{ sq. ft.;}$$

$$l = \frac{\text{A}}{\text{S}} = \frac{18{,}000}{60} = 300 \text{ ft.}$$

These dimensions would require a multiplane construction, five planes of 60 ft., or ten planes of 30 ft. each.

For, l = the sum of the lengths of all the planes on a machine. And it is particularly to be noted that A, the area, in all these formulæ and calcu-

lations is the area swept over by the planes in the flight of the machine.

The area of the wings, = F, is quite another matter, and is of no importance as a factor in the calculations.

By these formulæ the area of wings F will always come out right automatically, and similarly the ratio of their length and breadth will be correct.

Again, note particularly that S is the ahead speed of the machine in feet per second, and V the acceleration velocity of the air struck by the flying aeroplanes and deflected downwards.

M = the weight of the whole machine and its contents = T the upward thrust, and W is the weight of air deflected at velocity V under the planes per second. The following may serve as memoranda of the formulæ—

BC = perpendicular of triangle of the plane.

AB = base of triangle of the plane.

AC = hypotenuse of triangle of the plane, and is the chord of the plane.

$$V = S, \text{ the forward speed, } \times \frac{\text{perpendicular}}{\text{base}}.$$

$$T = \text{upward lift} = \frac{WV}{g};$$

$$W = \frac{T \times g}{V}, \text{ or } A\ V\ BC\ 0{\cdot}08;$$

A = l × S. l = sum of all the lengths of the planes on a machine;

A is also equal to $\frac{W}{V \times BC \times 0{\cdot}08}$;

$l = \frac{A}{S}$;

Another Process.

Reference may now be made to the older formulæ for the lift in aeroplanes.

Table II gives the pressure on a plate 1 ft. square or on a surface per square foot facing the blast of a wind.

The pressure $P = AV^2 \times 0025$ if V is the velocity of the wind and 0·08 the weight of air per cubic foot.

In appearance it is the same as (7), but it should be written—$P = AS^2 \times 0025$.

V in the formulæ used in this work is the velocity of the deflected air from a plane inclined to the direction of the wind—a totally different thing.

If S is speed ahead, P_1 the pressure on a plate perpendicular to the wind in lb. per square foot.

d = pressure in pounds on a plane surface moved obliquely against the air.

A = area of plane.

d_1 can be resolved into two components—a vertical one, the lift, and a horizontal one. The vertical one is represented by T, the horizontal one by D (see Fig. 13).

d_1 is the pressure normal to the plane.

The general formulæ in this older system deals with the angles of the triangles of the plane; hence we have the sine and cosine as factors.

For a plane perpendicular to the line of flight—

$$P_1 = \frac{0{\cdot}08 \text{ A } V^2}{32}.$$

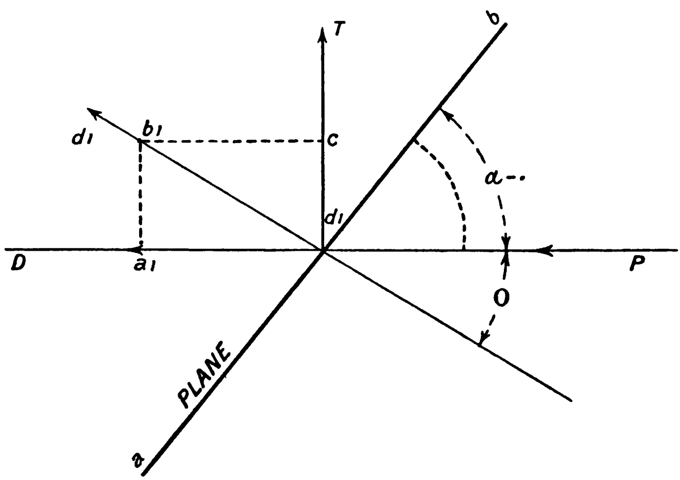

FIG. 13.

For a plane at an angle to the line of flight—

$$d = \frac{08 \text{ A } V^2 \sin a}{32},$$

which resolves into T, the lift—

$$T = \frac{{\cdot}08 \text{ A } V^2 \sin a \cos a}{32},$$

and D, sometimes called the drift, but really a head resistance—

$$D = \frac{\cdot 08\ A\ V^2 \sin^2 \alpha}{32}.$$

N.B.—V is in all these old formulæ the speed of the plane ahead.

TABLE II.—*Velocity and Pressure.*

Miles per hour.	Feet per minute.	Feet per second.	Wind pressure in pounds per square foot.
1	88	1·47	·005
2	176	2·93	·020
3	264	4·4	·044
4	352	5·87	·079
5	440	7·33	0·123
10	880	14·67	0·492
15	1320	22	1·107
20	1760	29·3	1·968
25	2200	36·6	3·075
30	2640	44	4·428
35	3080	51·3	6·027
40	3520	58·6	7·872
45	3960	66·0	9·963
50	4400	73·3	12·300
60	5280	88·0	17·712
70	6160	102·7	24·108
80	7040	117·3	31·488
100	8800	146·6	49·200

From these old formulæ can be approximately worked out the various principal dimensions of aeroplane machines, but the process is a most laborious one and requires considerable mathematical skill.

But its chief defect is that it does not reveal to the student the important fact that the weight of air deflected by the planes is the vital fact, and that it is the length of the sides of the triangle of the plane we have to deal with practically, not angles, sines and cosines, but lengths in feet and inches.

The only reference previously to the deflection of the air by the plane and its calculation is made by von Loessl in ascertaining the energy required for the lift.

He states that the flying plane displaces a mass of air = AS, area of the plane = A, S = its forward speed, and AS = q = quantity.

He assumes that the plane, in addition to displacing this quantity, forces an equal quantity out at the sides, and that the total quantity displaced is 2 q, and 2 q = 0·08. A.S. in lb. = W.

It is obvious that this assumption is merely a guess; however, he proceeds upon this to show how the energy required to move the plane is to be found:

$$\mathrm{E} = \frac{\mathrm{MV}^2}{2} = \frac{\mathrm{WV}^2}{2g} = \frac{\cdot 08,\ \mathrm{A\,V}^3}{32},$$

and since E also equals T × S, it follows that—

$$\text{Thrust, } T = \frac{\cdot 08 \times A \times S^2}{32}.$$

Generally speaking, the two methods of procedure lead to similar results, but the method herein given is the more direct, and the influence of the different factors is more obvious in the calculations, and the problems can be handled without reference to angles, sines, and cosines.

In using the older system a table is sometimes made out of lift in pounds per square foot of a plane at a speed of 60 ft. per second, as in Table III.

TABLE III.

Angle of incidence of plane.	Total lift in pounds per square foot at 60 ft. per sec.
0·5	0·19
1·0	0·38
1·5	0·57
2·0	0·75
3·0	1·13
4·0	1·51
5·0	1·89
6·0	2·26
7·0	2·64
8·0	3·02
9·0	3·10
10·0	3·17

Then from these values A, the surface area of planes, can be found by $A = \frac{m}{t}$, where m is total weight carried, and t is the lift in above table.

If $m = 1200$ lb. and $t = 3{\cdot}02$ for an angle of 8 degrees—

$$\text{then } A = \frac{1200}{3{\cdot}02} = 400 \text{ sq. ft. nearly.}$$

If now the breadth b of the plane were 6 ft. 6 in. the span would be $\frac{A}{b} = \frac{400}{6{\cdot}5} = 60$ ft., which would make a biplane of 30 ft. span.

With an ordinary man of about 150 lb. weight and an engine about same weight the total weight of the smallest machine for flying of any possible use would be about 550 lb.

A would with an angle of 10 degrees $= \frac{550}{3{\cdot}77} =$ 146 sq. ft., and with a 6·5 ft. breadth of plane the span would be—

$$\text{span} = \frac{146}{6{\cdot}5} = 22 \text{ ft. nearly.}$$

It is of little use to make the above table out below 4 degrees angle of incidence, for no practical planes can fly in still air at less than that angle unless the ahead speed is far beyond anything yet, or likely to be, accomplished. The table might, however, be extended to larger

angles up to 15 degrees, or even 18 degrees. The idea of the small angle of incidence is a relict of ancient aeronautics, surviving from the times of gliders.

From von Loessl's work a list is here given of the formulæ in which the angles of the triangle of the plane, instead of the sides of the triangle and their ratio are dealt with.

R_x = horizontal component on oblique plane.

R_y = lift of an oblique plane or vertical component.

R_1 = head resistance of a perpendicular plane.

R = head resistance of an oblique plane.

A = work ; g = gravity ; G = weight; F = plane area.

γ = weight per volume (per cubic foot or cubic metre).

v = speed of plane ahead.

Deductions from the Laws of the Resistance of the Air.*

$$R_x = R_y \tan a$$

$$A = \sqrt{\frac{g}{\gamma} \cdot \frac{R_y{}^3}{F} \cdot \frac{\sin a}{\cos^3 a}} = R_y\, v \tan a$$

$$R_y = \cos a \sqrt[3]{\frac{\gamma}{g} \cdot \frac{A^2 F}{\sin a}} = R_x \cot a = \frac{A \cot a}{v}$$

* See v. Loessl, 'Luftwiderstandsgesetze,' pp. 149 *et seq.*

$$F = \frac{g}{\gamma}\ \frac{R_x}{v^2 \sin^2 a} = \frac{g}{\gamma}\ \frac{A}{v^3 \sin^2 a} = \frac{g}{\gamma}\ \frac{R_y}{v^2 \sin a \cos a}$$

$$= \frac{g}{\gamma}\ \frac{R_y{}^3\ v^2 \tan a}{R_x{}^2 \cos^2 a} = \frac{g}{\gamma}\ \frac{R_y{}^3 \tan a}{A^2 \cos^2 a}$$

$$v = \sqrt{\frac{g}{\gamma}\ \frac{R_x}{F \sin^2 a}} = \sqrt[3]{\frac{g}{\gamma}\ \frac{A}{F \sin^2 a}}$$

$$= \sqrt{\frac{g}{\gamma}\ \frac{R_y}{F \sin a \cos a}} = \frac{A \cot a}{R_y}$$

$$\tan a = \frac{R_x}{R_y} = \frac{A}{R_y v}$$

$$\sin a = \sqrt{\frac{g}{\gamma}\ \frac{R_x}{Fv^2}} = \sqrt{\frac{g}{\gamma}\ \frac{A}{Fv^3}}$$

$$\sin 2\,a = \frac{g}{\gamma}\ \frac{2R_y}{Fv^2}$$

$$\sin a \cos a = \frac{g}{\gamma}\ \frac{R_y}{Fv^2}$$

$$\frac{\cos^2 a}{\tan a} = \frac{g}{\gamma}\ \frac{R^3{}_y}{FA^2}$$

Work and Energy.

We will now revert to the system employed in this work and deal with the question of work and energy.

The work done by the plane is to deflect a mass of air of weight W, impressing a velocity V downwards upon it.

The energy expended in this work is $\frac{WV^2}{2g}$, and

does not require to be divided up into two components.

In our calculations to find the principal dimensions of the aeroplanes we always find W and V two necessary factors, so that we have no difficulty in finding E, the energy expended in lift alone, and added to this energy is that required to force the plane ahead at speed S; $E = T \times S$, neglecting friction and resistances.

Taking the first example which we calculated out for a machine to carry 800 lb. 60 ft. per second = S, we found $W = 2560$ lb., and $V = 10$ ft. per second.

The energy in the thrust which is converted into lift by the deflection of 2560 lb. of air at a velocity $V = 10$ ft. per second is $= \frac{WV^2}{2g}$,

$$= E = \frac{2560 \times 10 \times 10}{64} = 4000 \text{ ft. lb. per second}$$

$$= \text{h.p.} = \frac{4000}{550} = 7{\cdot}3 \text{ horse-power.}$$

In the other example we found with same weight to carry and same speed, but with different ratio of the triangle of the plane and shorter span—

$W = 2133$.

$V = 12$ ft. per second.

$$E = \frac{2133 \times 12 \times 12}{64} = 4800 \text{ ft. lb. per second,}$$

and $\text{HP} = \frac{4800}{550} = 8{\cdot}8$ nearly, so that if we must have a small machine with short wings we must pay the price of a greater horse-power to work it.

These horse-powers are the net theoretical powers for lift alone not including losses. In practice they would be at least doubled to cover the losses in lifting, and a further power added to cover head resistances, friction, and drag of about 50 per cent.

If P is the thrust then $P \times S$ is the total energy required to drive the machine ahead.

A quantity of air is thrown astern of the machine by the propeller with a thrust equal to P, that pushing the machine ahead, and a velocity v. The power expended upon this work is $P \times v$, and the total work is therefore—

$P \times (S + v)$, and horse-power =

$$\text{h.p.} = \frac{P \times (S + v)}{550} \quad . \quad . \quad . \quad (11)$$

R = head resistance, the horse power for which

$$\text{h.p.} = \frac{S \times R}{550} \quad . \quad . \quad . \quad . \quad (12)$$

If W = lb. weight of air driven astern by the propeller, the energy lost in slip $= e = \frac{w \times v^2}{2g}$;

P = the propeller thrust;

v = slip or propeller acceleration of air;

S = forward speed.
First, h.p. in thrust = P × S ÷ 550.
Second, h.p. in slip = P × v ÷ 550.
Third, total h.p. = P × (v + S) ÷ 550.
Fourth, h.p. in lifting alone = $\dfrac{\mathrm{WV}^2}{2\,g\,550}$.

Propeller thrust in lb. per h.p. in first = $\dfrac{550}{\mathrm{S}}$.

H.p. in overcoming resistance friction, lift and slip =

$$\text{H.p.} = \frac{\mathrm{S} \times \mathrm{R}}{550} + \frac{\mathrm{W} \times \mathrm{V}^2}{2\,g \times 550} + \frac{w\,v^2}{2\,g\,550} \quad (13)$$

It has been shown in the foregoing that the horse-power expended in the lift can be calculated from W, the weight of air deflected down by the planes, and V, its acceleration velocity, to be equal to $\dfrac{\mathrm{WV}^2}{2\ g\ \times\ 550}$, which in one case calculated amounted to 8·8 horse-power for lift alone.

In order to show how to deal with the expenditure of power on the different items which go to make up the total power expended on the machine in flight at 60 ft. per second let the power expended on lift be that found as above—8·8 horse-power.

Let the propeller thrust be 240 lb. = P, and the slip or real acceleration of the propeller be v = 30 ft. per second, then—

by (11) $\text{H.p. total} = \frac{P \times (s + v)}{550} = \frac{240\,(60 + 30)}{550} = 40;$

h.p. = the horse-power propelling =

$$\frac{P \times S}{550} = \frac{240 \times 60}{550} = 27;$$

h.p._1 = horse-power in slip =

$$\frac{P \times v}{550} = \frac{30 \times 240}{550} = 13.$$

Of the 27 horse-power propelling the machine we have already found 8·8 horse-power taken for lift, hence 27 − 8·8, = 18·2 h.p._2, is expended in overcoming head-resistance, friction, drag, and other work.

We now make a balance-sheet of income and expenditure of power.

Total horse-power h.p. = brake-horse-power	40	*H.p. in various works.*	
		H.p. in lift	8·8
		H.p._1 in slip	13
		H.p._2 in resistance, drag, and friction	18·2
B.h.p.	40	Total h.p.	40

The thrust per horse-power of any propeller under any conditions whatever can never exceed $\frac{550}{s}$, a fact apparently unknown to some of the makers of patent propellers for aeroplanes.

At 60 ft. per second the thrust per horse-power cannot exceed $\frac{550}{60} = 9$ lb. per horse-power (that

is horse-power propelling $= \frac{\text{P} \times \text{S}}{550}$, and if we take total horse-power, that is $= \frac{\text{P}(\text{S} + v)}{550}$, then the thrust per total horse-power cannot exceed under any circumstances $\frac{550}{(\text{S} + v)}$.

In this case $\frac{550}{90} = 6$ lb. per horse-power (total). When it is claimed for a propeller that it gives a phenomenally high thrust per horse-power the statement is valueless unless the speed is also given and the slip stated.

CHAPTER V

THE CURVES OF THE AEROPLANE

A FLAT plane is inefficient, for it accelerates the air too rapidly at the entry, and the air is turbulent in its passage under a flat plane and also on the flat back.

A slight curvature is a great improvement, as the air is gradually accelerated below, and follows the curved back without much turbulence.

Consider a curved plane driven through the atmosphere, as in Fig. 14; the air coming beneath the plane is driven downwards at a rate of velocity V, as explained in a previous chapter. It does not matter how far downwards the effect extends, or what becomes of the air after it leaves the plane at C. If the *rate* of deflection while it is under the plane is = V that is all we need know.

The air above the plane is also pulled downwards, the two streams meeting at C, so that the reaction which lifts the plane is partly due to the push on the under side and partly to the pull on the upper side.

But the pull on the upper side is small, for the atmosphere pressure of 2116 lb. on the square foot cause the air above the plane to follow closely the back of the plane. Any pull upwards on the back of the plane would be due to a reduction of this enormous atmospheric pressure.

A difference of pressure in the atmosphere

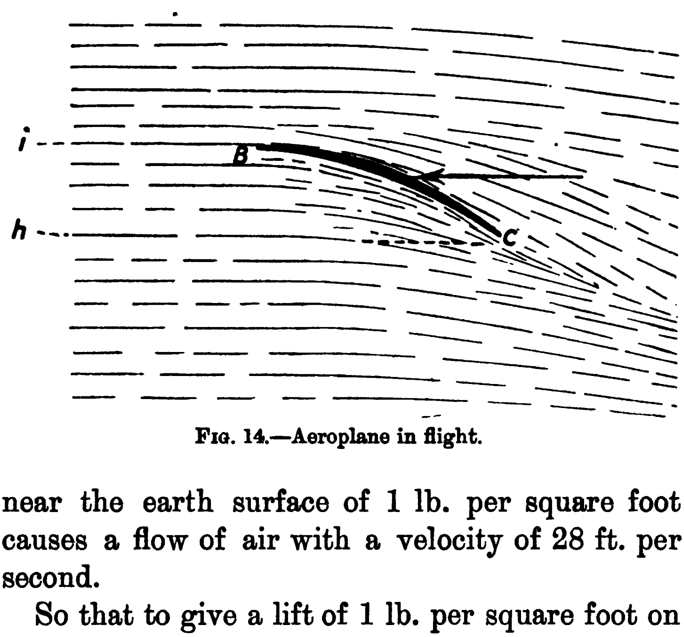

Fig. 14.—Aeroplane in flight.

near the earth surface of 1 lb. per square foot causes a flow of air with a velocity of 28 ft. per second.

So that to give a lift of 1 lb. per square foot on the back of the plane the downward thrust of the plane would need to be a little over 28 ft. per second, whereas in few cases does it ever exceed 10 ft. per second.

The head is as the velocity squared, so that the suction on the back of plane at a deflection of 10 ft. per second would be only a little over 2 oz. per square foot, as that difference of pressure would bring down the air to follow the back of the plane.

Thus in experiments on planes the effect on the back of the plane is small and negligible, more so because not only does it cause a small lift only, but it also causes a drag on the plane, for suction is due to the action of the forward motion of the plane, the reaction of which must be backwards as well as upwards. For these reasons we calculate only in the positive pressure on the under side of the plane at ordinary deflection velocity.

With very high velocities of v, however, the suction on the back of the plane would be considerable, and is so in winged flying animals when the wing-beats are so high as to produce a musical note, like the hum of the bee or humming-bird. In aeroplane construction the back of the blade should be a curve to allow of the undisturbed sliding of the surface through the air.

Figs. 15 and 16 show the best effects as planes flying through the air. In no case should the planes deflect the air upwards. Any action deflecting the air *up* must have a reaction forcing the plane *down*.

A form of blade shown in Fig. 17 is therefore bad for a flying plane; so also is that shown in

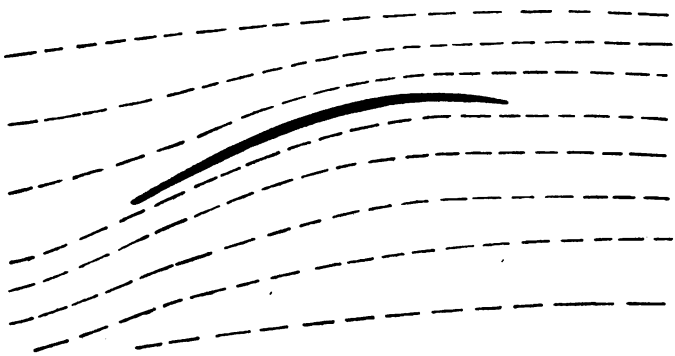

Fig. 15.—Aeroplane section.

Fig. 18. Both of them cause an upward deflection, as shown by the stream-lines.

These bad forms have what is called a "dipping front edge."

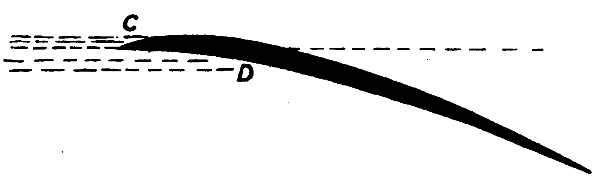

Fig. 16.—Aeroplane section.

It has repeatedly been claimed that such a bad form gives a greater lift when the plane is held in a moving current of air and not allowed to move horizontally. But it has never been proved that

this form gives a greater lift on a plane flying through still air, and that is the condition under which planes act in flying-machines.

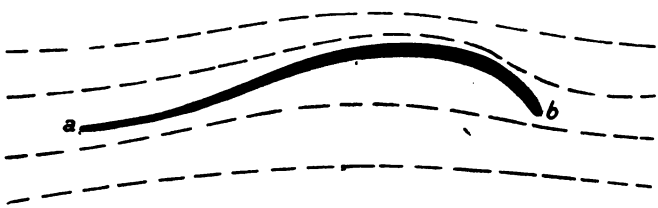

FIG. 17.

The dipping front edge is not very prominent in the best examples of flying-machines which

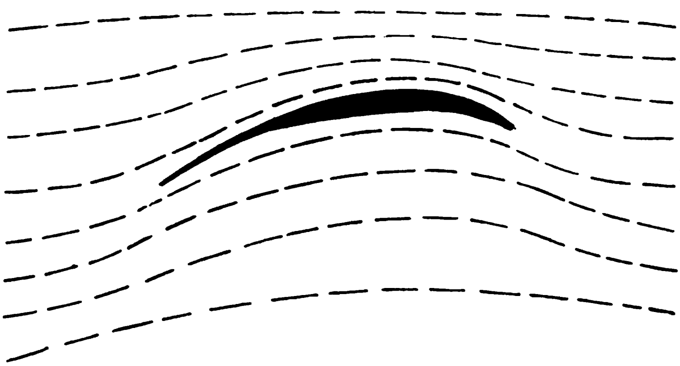

FIG. 18.

have been used to win the large prizes, while none of them with pronounced dipping edges have ever flown at all with success.

The best curve in practice seems to be pretty near that shown in Fig. 19.

The three straight sides of the triangle of the plane—*ab* the base, *bc* the perpendicular, and *ac* the plane—are shown. Taking *ac* as a chord, the curve is given by the abscissa, showing the curve of the under face of the plane; the upper curve is made so that the plane is thickened towards the front edge, and then tapers to a point, as in Fig. 16.

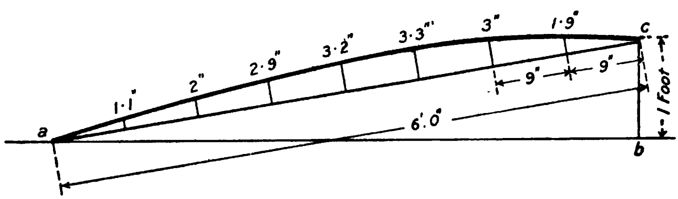

FIG. 19.—Curve of aeroplane.

The fact in this matter is that no one curve is "the best." A "best curve" could be found only for one plane working always at the same angle of incline to the line of flight, but in practice the plane has to work at different angles to the line of flight—sometimes a small angle, sometimes with a large angle; hence it is that the curve must be a medium curve to suit the varying angles.

Very likely in future some curve will be found by experience to meet the requirements, but

meanwhile very good results are obtained with a curve like Fig. 19.

The form of dipping-edge aeroplane which has been tested in an air blast and found to give best results is not anything like that absurd section shown in Fig. 17. This section, however, is a copy from a limelight illustration shown by a lecturer on "aviation" to an admiring audience as the section of the very best design.

A plane may have a dipping front edge as shown in Fig. 20, in which the "dip" is on the back of the blade only. This form of blade is due to Mr. Horatio Phillips. This dip, however, must not be carried too far; if exaggerated it causes resistance, but it lends itself to the construction of the wings, for it provides room for the purlins in the wing shown cross-hatched (Fig. 20).

There should be no dip on the under surface.

In connection with monoplanes a point which has elicited great interest and aroused the curiosity of amateur mechanics is the "dihedral angle," shown in Fig. 21. For some reason or another, not apparent and not stated, some constructors have given the wings of a monoplane this angle more or less. It structurally strengthens the machine against damage to the upper ties when the machine bumps on the ground, but it weakens

it as a structure generally. When in flight the strain comes on the lower ties, so that the wings tend to collapse upwards; this has happened. It

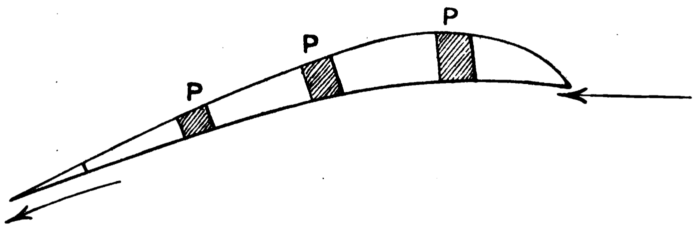

FIG. 20.—Aeroplane surfaces.

perhaps steadies the machine when on a downward glide, but that is doubtful.

The best arrangement is a straight plane for a machine which moves through space of three

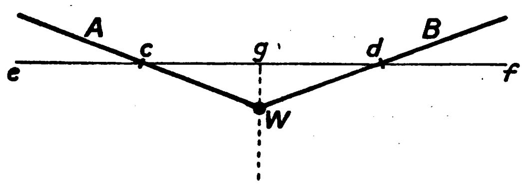

FIG. 21.—Aeroplanes at a "dihedral angle."

dimensions, and a straight plane is a stronger structure mechanically.

In Fig. 22 are shown sections of the aeroplane wings in actual use.

The dipping front edge on the back is evident. The dip on the under surface is, however, only

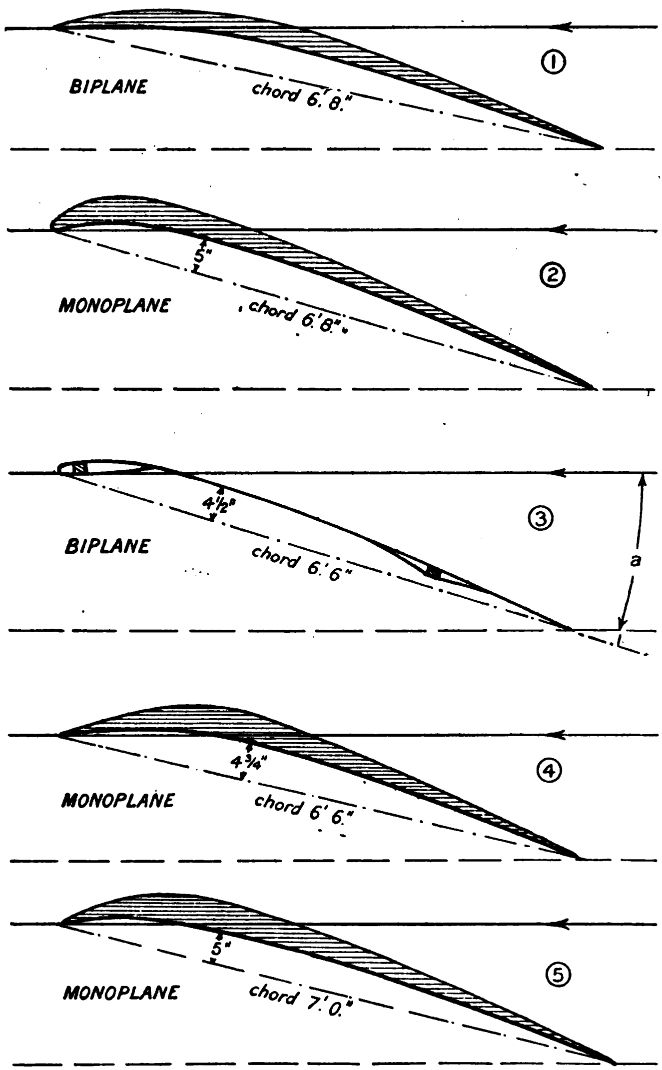

Fig. 22.—Sections of aeroplanes in practice.

relative to the chord, but as the chord must in flight be at an angle *a* to the line of flight, the dip relative to the line of flight is nothing at some angle. This angle will be that of highest efficiency of the plane. The arrow line drawn on each of the sections represents the line of flight, making an angle with the chord.

The arrow line is drawn so that it enters the edge parallel to the dip in each case, and the angle is *a*, as shown at 3.

CHAPTER VI

AEROPLANE CENTRES OF GRAVITY; BALANCING; STEERING

THE elementary aeroplane machine is shown in Fig. 23 of biplane construction. 1 and 2 are the two planes. The gap between them is usually equal to their width fore and aft. 4 is a horizontal plane, which can be inclined at any desired angle by the aviator, in order to elevate or depress the front edge of the main planes and so alter their angle to the line of flight in order to give more or less lift. Four planes are shown forming the tail. It has two vertical planes for steering to port or starboard, and two horizontal planes to support the weight of the tail. 5 and 6 are landing wheels and skid. The machine runs along the ground on the wheels until it gathers enough speed to rise.

This arrangement is, of course, not compulsory; variations are possible. The front plane for elevating may be left out and the two horizontal

planes in the tail used for elevating or depressing the main planes. This is shown in Figs. 24 and 25. This is quite a favourite arrangement.

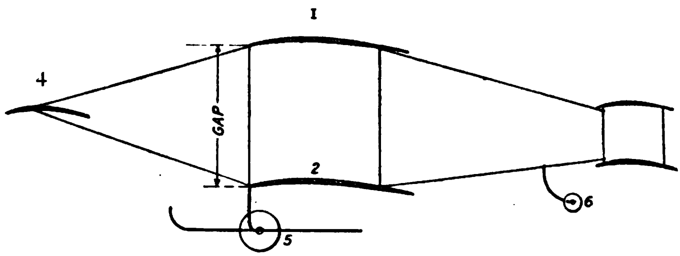

FIG. 23.—Elements of biplane.

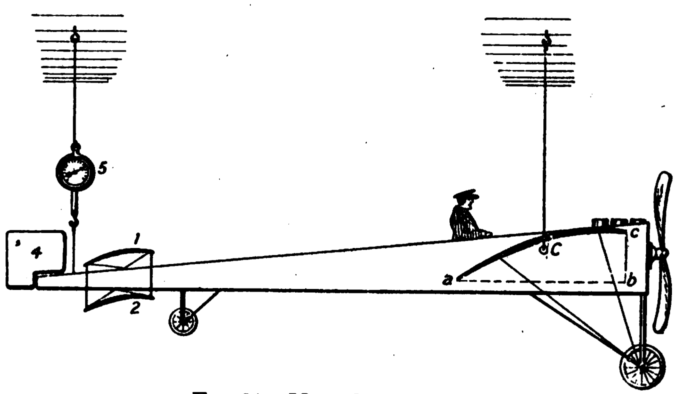

FIG. 24.—Monoplane and tail.

In Fig. 24, 4 is the rudder for steering, 1 and 2 the elevating planes. The tail planes, 1 and 2, in these designs must be calculated to support the weight of the tail by their reaction. The

weight to be thus supported is found experimentally by suspending the machine as shown, when the spring balance, 5, will show what weight the tail planes have to carry.

The tail requires quite as much care, skill, and attention as the head of the machine, for if the tail is faulty in design the machine will be cranky and erratic.

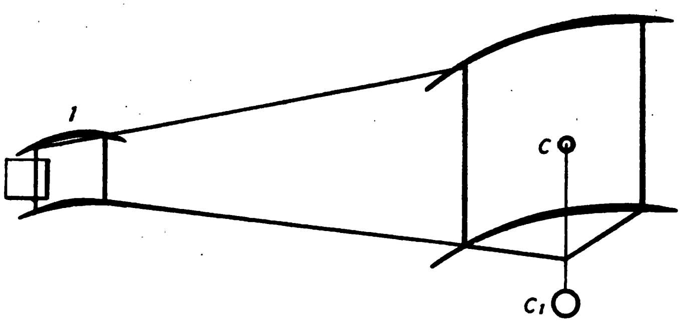

FIG. 25.—Biplane with tail.

Perhaps the only improvement made in flying machines of aeroplane type since Langley's time is the balancing invention of the Wright Brothers. To balance the planes of wide span in mid air is a difficult problem. It is solved on the Wright Bros.' principle by the pilot or aviator being given the power to alter the angle of the planes at their tips by means of a lever and connecting wires or cords (Fig. 26).

When the aviator, ever on the alert, notices the

plane dip down at end *a*, he by the lever pulls the corner of the wing down at *a*. This gives to that end of the wings a preponderating lift, which checks the downward move, and so with the other end. This simple device acts very well, and has been copied by nearly all machine makers. Others, however, have tried other means for operating on the same principle. Some use little aeroplanes or ailerons out at the tips as shown at A and A, Fig.

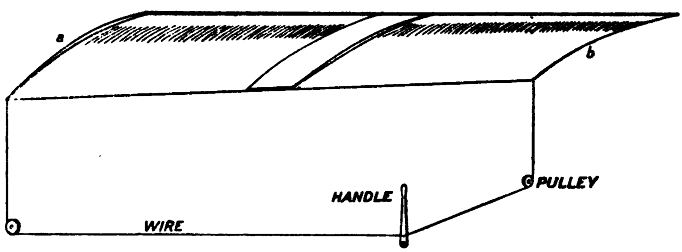

FIG. 26.—Wing warping.

31; by elevating and depressing these a balance can be maintained in the same way as by bending the wing-tips. Another makes sliding planes on the tips, so that by sliding them out, or in, the length of the plane is increased at one end and decreased at the other, and so balancing.

There are many proposals for balancing, but nearly all of them rely upon the alertness and muscular power of the aviator.

It is astonishing that this lateral balancing has

not been made automatic; there is no difficulty in the way of doing so. Many simple mechanical devices could be easily designed to give an automatic lateral balance. And automatic lateral balance must be accomplished before the aeroplane can be considered as a practical machine.

Elevating and steering the course must of course be controlled personally by the aviator, wherefore the importance of good design in the tail used for steering and elevating the machine.

In the Wright Bros.' first machines they discarded the tail as being superfluous, and with their machine, without tails, they performed all the movements and evolutions quite as well as any machine with a tail.

Birds' tails can also be dispensed with. Few birds experience any difficulty in flying without a tail. The tails of pigeons can be closely clipped; they will fly apparently quite as well as before, and so with other birds. But if one wing is clipped a little bit shorter at the tip than the other wing, then there appears to be great difficulty in flight.

If the tails can be dispensed with in machines a considerable saving in weight would result.

Warping the wings can be used for steering. For instance, if the right wing is warped at the tip and the left wing unwarped, the machine

swings round to the right, for the tip of the right wing offers more resistance then, to the forward motion, and tends to rise, but in swinging round the left wing makes greater speed, which also tends to raise it higher. The rising effort is therefore equalised to some extent, the right wing lifting by its greater angle and the left by its greater velocity.

This is the substance of the Wright Bros.' invention of wing warping, and by its means a tailless machine can be steered. Tails are prominent features in the monoplane machines and also in the Farman machine, where they are designed for steering and elevating.

The steering and elevating of machines as presently practised is certainly very primitive, and something much more positive and certain of control is very desirable. The present system throws far too much responsibility on the pilot, and is too much at the mercy of the variable winds.

In the present stage of progress it seems sufficient for the aviators to have a machine which can be controlled entirely by the pilot without any mechanism which would add complication to the machine, such as automatic balancing, and for the purpose of sporting and aviation meetings they do wonderfully well, but the flying machine,

if it is ever to become a useful carrier of mails, passengers, or military men, must do a great deal more than anything attempted in sport or prize winning, and much invention is required to improve it and bring it into a really useful, practical machine.

The problems of the flying machine are often compared to those of the early days of motor cars, when some people thought the motor car could never be made a success. And the rapid development of the motor car is held up as an example of what we may expect in the flying machine business.

But the two cases are totally different. In the motor car there were no new problems; cars on wheels, on common roads, were no new means of locomotion, and the elements of the highest developments in motor cars even to-day are old inventions. The rapid development was, in fact, due to there being no great discoveries or inventions needed in its design. It only required money and engineering ability to adapt the inventions, which were well known and ready for application, coupled with the important conditions that the motor car was a desirable thing itself among wealthy people, and the risks taken in driving it on the roads were trivial and more exciting and amusing than anything else.

The flying machine is another proposition. Locomotion in the air is entirely new, although the aeroplane idea is by no means new. About all we have got to start with is the engine, propeller and wings, and many difficult problems abound, all of which will require invention of a high order, besides engineering skill and money for their successful solution.

Many entirely original devices must be discovered to solve the problems of balancing, steering, elevating, starting, and landing, and also to enable the machine to battle with the winds successfully.

The problem much resembles that of the steam turbine. These machines were made and their principles fully understood more than half a century before they became practically useful engines. Gradually discovery after discovery was made, and inventions devised to remedy the practical defects and overcome the difficulties; mistakes were made, but in time it became a successful prime mover.

Experience with other steam motors was of no avail. A new field of operations had been entered, and the new problems were difficult and called for far more than ordinary engineering ability and factory methods and money to solve them.

Similarly with the flying machine, we are in a new country without a map, no roads, and nothing but the primitive machine at present known, as a practical guide, together with scientific principles to help in the opening of the new ground.

The improvement of the flying machine is no small undertaking even by the inventor with high scientific attainments. It is a costly machine to experiment with on the scale necessary for reliable results.

For these reasons it seems that it would be better for the progress of the flying machine if the many bodies and individuals who have devoted themselves to the encouragement of the development of the machine would devise means for the encouragement of the inventor. To bring out the inventive ability where it exists is what is required. There be many patentees but few inventors. The patentees are in the field in battalions, but no great invention has as yet appeared, except Wright Bros.' wing-warping device. It was the intention of the author to make references to some of the patent specifications for improvements in aeroplanes, especially to those for balancing and steering. There are many of them, but 90 per cent. of them are the products of imaginative minds with no knowledge of mechanics and less of aeronautics; of the other

10 per cent., inquiry fails to find any results of any trials made with them. And they do not look like propositions which would be of any use.

This dearth of inventive ability in this field of activity is most remarkably shown in the literature of the subject. Probably £50,000 has been offered to, and won by, aeroplane drivers as prizes, prizes originally intended to encourage and promote "aviation." The results, so far as improvements on the machines go, is nothing, and the names of the prize-winners do not figure among inventors.

The diagrams shown herein will convey a clear idea as to what has been done in changing the designs of the present aeroplanes. Fig. 27 represents the tailless Wright Bros.' machine, with elevating planes on a front outrigger, with the propeller or propellers behind.

The machine can be controlled by wing-warping only, both as to balancing and steering, the elevating being effected by the small front planes.

The Wright machine has, however, been fitted with vertical steering planes behind the main planes, as shown in Fig. 28. These machines had two propellers of large diameter driven at comparatively low speeds by chain gearing. They were therefore very economical of power, the Wright Bros. doing with an engine of 25 horse-

power what others are now doing with 50 horse-power, except that they required assistance to start up.

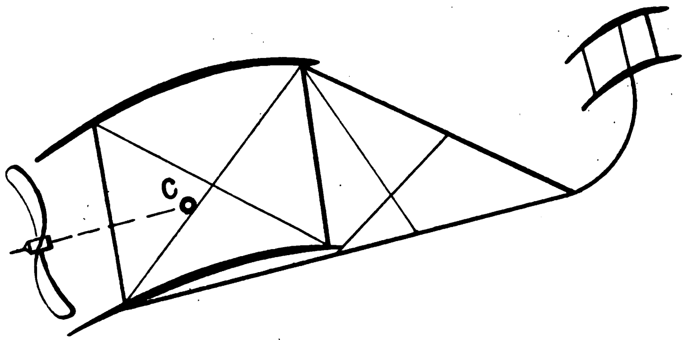

FIG. 27.—Tailless biplane.

Fig. 29 represents a biplane with a tail. This tail consists of supporting and elevating planes 1,

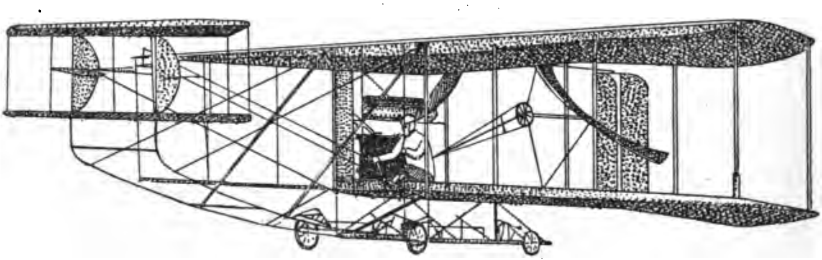

FIG. 28.—Wright Bros.' biplane.

with a vertical rudder 4, both controlled by the driver. The propeller is shown in front of the main planes, but in most biplanes it is behind

the main planes. Its position is a matter of convenience, as it is equally efficient in front or behind.

The tailed biplane of Henry Farman is shown in Fig. 30, where the tail consists of two horizontal planes for elevating, and two vertical planes for steering, and a front plane on an outrigger for elevating.

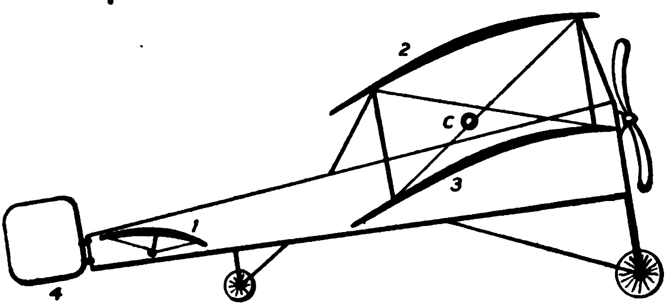

FIG. 29.—Tailed biplane.

The diagrammatic sketches of the Farman machine, Figs. 31, 32, as used by M. Paulhan in winning the £10,000 prize, London to Manchester flight, will show the general construction of present-day aeroplanes, with principal dimensions.

Instead of warping the wings we have hinged flaps A on the outer ends of the main planes to be used for balancing. A front plane is used for elevating, assisted by a hinged flap S on the end of the tail, called a "super-elevator." The tail

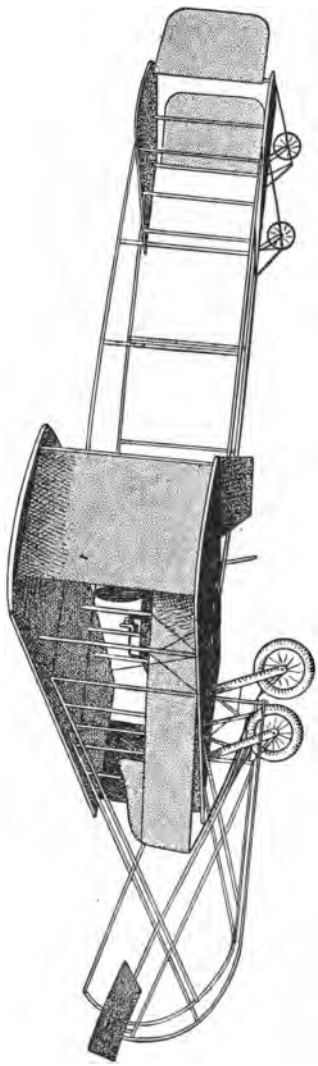

Fig. 30.—Farman biplane.

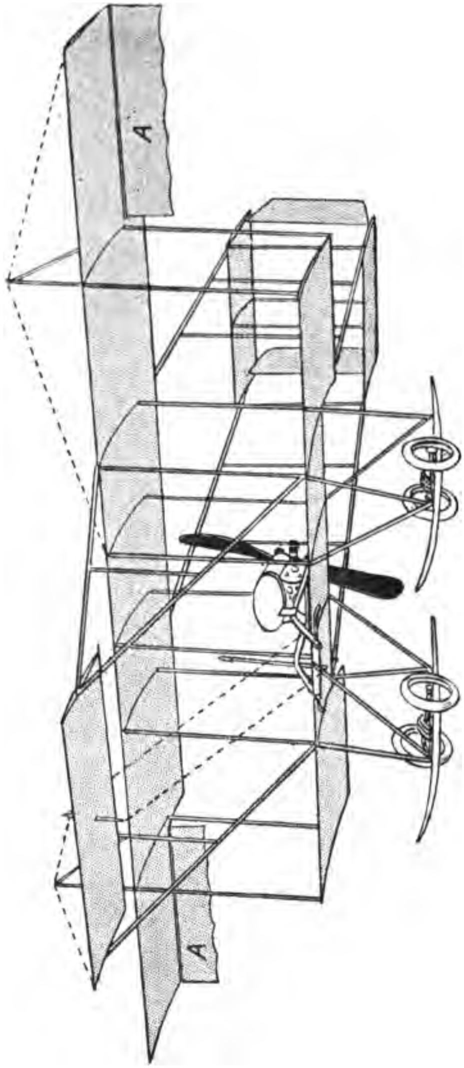

Fig. 81.—Farman biplane.

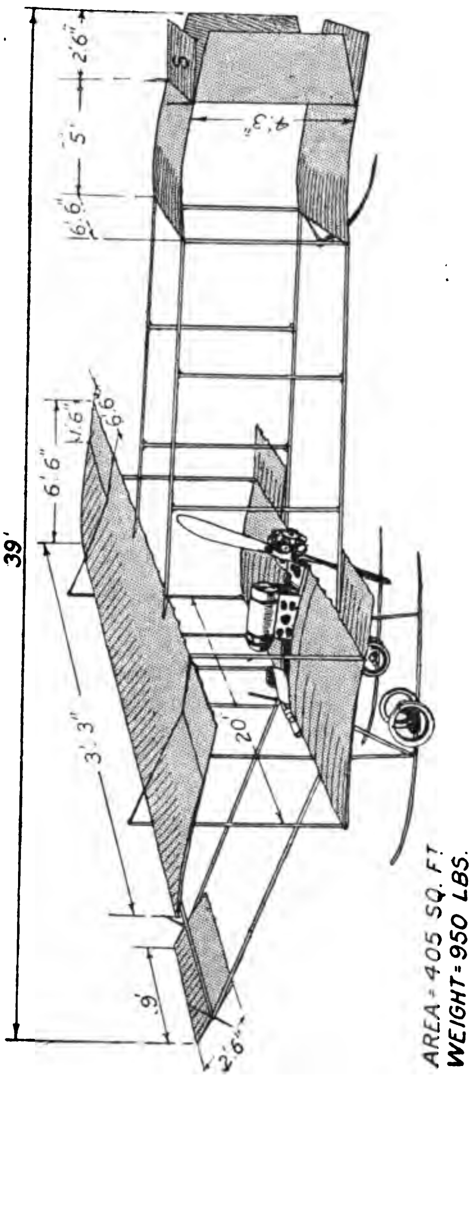

FIG. 32.—Farman biplane.

is, as it ought to be, of ample dimensions, and is carried on four rods of a very good mechanical design, without any fanciful attempts to make it like a steel girder bridge.

The front elevator is also of ample dimensions, area 22 sq. ft., and carried on a simple outrigger.

The upper main plane is longer by the length of the "Ailerons" or flaps A A. This gives an increased effect to the upper main plane and more powerful balancing control.

In fact, in this machine the elements of control have been made as powerful as possible without adding too much weight, with the result that the machine is well under the control of the pilot.

The monoplane machine is shown in Fig. 24 with a long tail, a pair of elevating and supporting planes, 1 and 2, and a rudder, 4. The long tail enables these tail planes to be made smaller than they might be with a short tail, but it is very doubtful if a long tail is much advantage. Large elevating and steering planes in a short tail would be better. However, this is a question which experience alone will settle.

Fig. 33 shows a monoplane of usual design in perspective view, with a long tail; the middle portion of the horizontal plane on the tail end is fixed and serves to carry the weight of the tail; its two extremities are movable for elevating

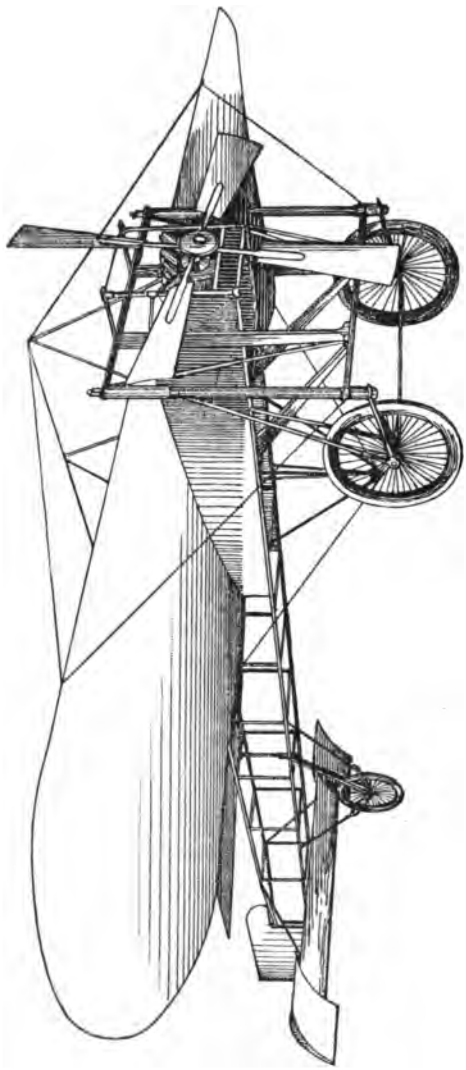

Fig. 33.—Monoplane (Bleriot).

purposes. The tie wires are not shown, but an idea of their number and arrangement may be gathered from Fig. 34.

The biplane is the better machine in every way, and has been proved so in practice. The idea of the monoplane was, that a small, cheap, machine might on that design be produced, but that is based on a fallacy; the planes and tail of a machine are not expensive, but the engine, propeller and other power plant is very expensive. A small machine may have small wings, but it requires larger engine power than the larger machine.

Triplanes and multiplanes may in future be developed, but presently they have not been a success. Probably for large powers the Farman type of machine, Figs. 30 and 31, will develop into two biplanes in tandem. The tail will grow into another biplane of equal size to the front biplane, with two pilots, one on each biplane.

The flying machine, floating submerged in a mobile fluid like air, is continually in movement, swaying, swinging and swerving. In order to have stability the first requisite is that all the motions should move round its centre of gravity; and the thrust of the propeller should pass through the centre of gravity and pressure also.

The centre of gravity in the biplane is shown

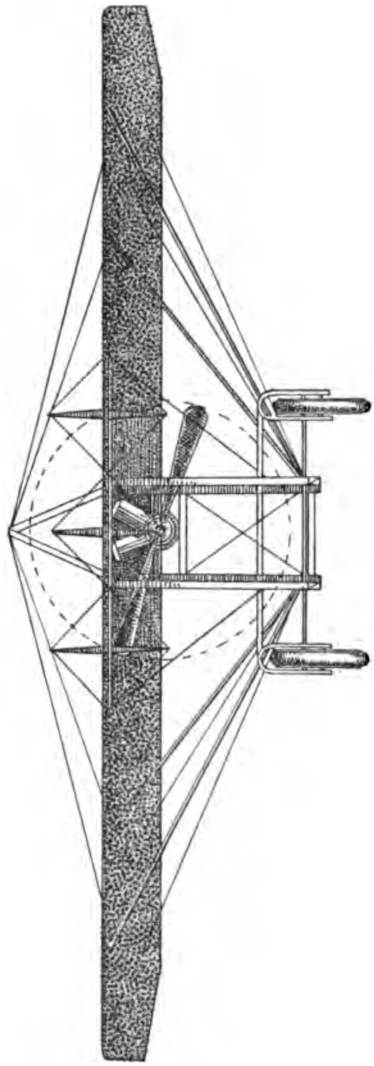

FIG. 34.—Front view, monoplane.

at C in Fig. 27, with the propeller shaft passing through it.

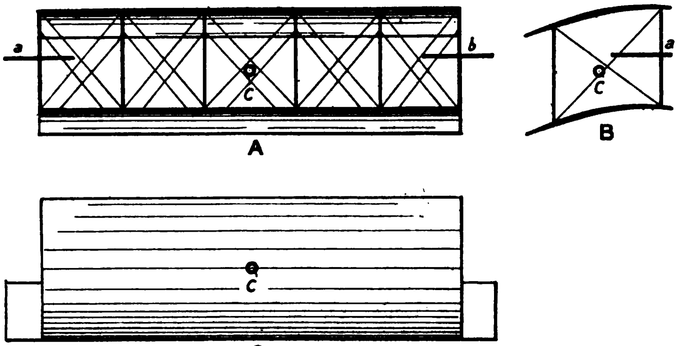

FIG. 35.—Centre of gravity of biplane.

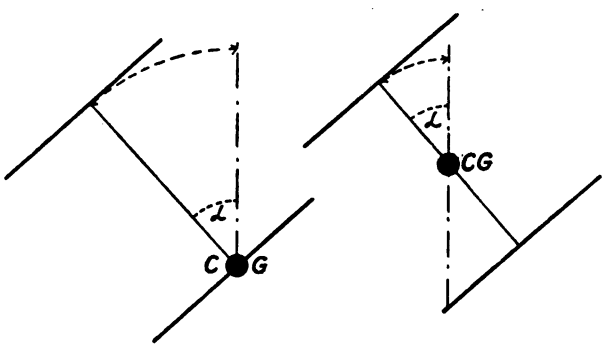

FIG. 36.—Centre of gravity.

In Fig. 35 the centre of gravity is shown in three views, A, B, C, steering, balancing and elevating movements all taking place around the centre C.

In Fig. 25 C is the centre of gravity of a tailed biplane.

The movement taking place around the centre of gravity C is much less than it would be around a lower centre of gravity C_1, when the planes are elevated or depressed or canted over. This is shown in Fig. 35, where the centre of gravity is midway between the planes in one view and on the lower plane in the other view.

DETAILS OF MACHINES AT OLYMPIA.

Two columns have been added showing pounds of weight of machine per horse-power and pounds of machine per square foot of surface of wings only. It will be observed, however, that some small-winged machines have large rudders, elevating and tail planes. And tail planes and elevating planes add to the wing surface considerably.

In the weight of the machine given it is not stated whether it includes fuel, and if it does so, for what time the fuel is calculated to last.

The weight does not include a pilot, passengers, nor cargo.

Some of the machines could carry one man of light weight and fuel for half an hour only.

Others could carry as much as half their own weight, fuel included for two hours' flight.

DETAILS OF MACHINES

(From *Analysis of Aero-*

Name.	Type.	Spread of wing.	Depth of wing.	Rudder.	Elevator.	Tail.	Length.
Avis	Mono	28′	6′ 4″	14 sq. ft. and 22 sq. ft. (cruciform and of irregular shape)		None	27′
Blériot (Type XI)	Mono	25′	6′ 7″	2′ 9″ × 2′ 6″	2′ 2″ × 2′ 9″ (one each end of tail)	12′ 0″ × 2′ 9″	26′
Demoiselle (Dutheil Chalmers)	Mono	21′	6′ 6″	9 sq. ft. and 19 sq. ft. (cruciform and of irregular shape)		None	23′
Demoiselle (Clément)	Mono	18′	6′ 10″	13 sq. ft. and 18 sq. ft. (cruciform and of irregular shape)		None	20′
Demoiselle (Mann and Overton)	Mono	20′	6′ 6″	10½ sq. ft. and 16 sq. ft. (cruciform and of irregular shape)		None	20′
Farman	Bi (*b*)	33′	6′ 6″	4′ 0″ × 4′ 3″	9′ 0″ × 2′ 6″ (front) 7′ 0″ × 2′ 6″ (back)	6′ 6″ × 5′ 0″ (biplane)	39′
G. and J.	Bi (*c*)	30′	5′ 6″	5′ 0″ × 4′ 6″	12′ 0″ × 3′ 0″	10′ 0″ × 5′ 0″ (monoplane)	31′
Grégoire-Gyp	Mono	34′	7′ 4″	4⅛ sq. ft.	10 sq. ft. (triangular)	76 sq. ft. as empennage 9′ 6″ long	34′
Humber (Le Blon)	Mono	29′	6′ 6″	3′ 0″ × 2′ 0″	2′ 9″ × 2′ 0″ (one each end of tail)	6′ 0″ × 2′ 9″	26′
Humber Biplane	Bi	41′ 6″	6′ 0″	12 sq. ft. (of irregular shape)	32½ sq. ft.	8′ × 2′ 3″ as empennage	36′
Humber (Lovelace)	Mono	33′ 3″	6′ 9″	10¼ sq. ft. (irregular shape)	32½ sq. ft. (irregular shape)	8′ 0″ × 2′ 3″ each side as empennage	26′ 8″
Handley Page	Mono	30′	6′ 0″ (tapering to point)	7½ sq. ft. (triangular)	6 sq. ft. (triangular)	8 sq. ft. (triangular)	21′

EXHIBITED, 1910.

' Flight.')

planes at Olympia.

Surface.	Weight.	H.P.	Propeller diameter.	Propeller pitch.	R.P.M.	lb. H.P.	lb. sq. ft.	Remarks.
sq. ft.	lb.							
160	430	35	(T) 6′ 0″	2′ 3″	1200	12·3	2·7	—
156	485	35	(T) 6′ 8″	3′ 0″	1200	13·9	3·1	—
135	325	35	(T) 6′ 6″	3′ 6″	1200	9	2·5	—
108	230	30	(T) 6′ 6″	2′ 3″	1200	7	2·1	—
133	340	30	(T) 6′ 6″	2′ 6″	1400	11·3	2·6	—
476	1050	40	(P) 6′ 7″	—	1000	26	2·2	—
426	660	60	(P) 9′ 0″	10′ 0″	600	11	1·3	—
377	500	30–40	(T) 7′ 0″	—	1600	14	1·3	Doubtful.
192	490	30	(T) 6′ 6″	3′ 6″	1200	16·3	2·5	—
482	not given	50	(T) 6′ 6″	not given	1200	—	—	—
210	not given	50	(T) 7′ 0″	—	1200	—	—	—
150	250	20–25	(T) 6′ 6″	not fixed	1800	10	1·6	—

Name.	Type.	Spread of wing.	Depth of wing.	Rudder.	Elevator.	Tail.	Length.
Howard-Wright	Mono	27′	6′ 6″	3′ 0″ × 2′ 6″	3′ 0″ × 3′ 0″ (at each end of tail)	6′ 0″ × 3′ 0″	29′
Lane (1 seat)	Mono	30′	6′ 3″	2′ 3″ × 2′ 8″	3′ 0″ × 4′ 0″ (2 above tail)	8′ 8″ × 3′ 0″	24′
Lane (2 seats)	Mono	36′ 6″	8′ 0″	2′ 6″ × 3′ 3″	8′ 8″ × 3′ 0″	10′ 0″ × 3′ 0″	24′
Mulliner	Mono	33′	6′ 6″	2′ 0″ × 2′ 0″ (approx.)	15 sq. ft. (triangular)	14 sq. ft. as empennage	27′
Ornis	Mono	30′	6′ 0″	3′ 2″ × 2′ 0″	2′ 9″ × 3′ 0″ (one each end of tail)	6′ 0″ × 3′ 0″	28′
Roe	Tri	20′ or 26′	3′ 6″	2′ 4″ × 3′ 0″	All planes act as elevators	8′ 4″ × 3′ 0″ (triplane)	23′
Short-Wright	Bi (*d*)	40′	6′ 3″	5′ 4″ × 1′ 7″ (twin)	15′ 0″ × 3′ 0″ (biplane)	None	27′ 9″
Short (Moore-Brabazon)	Bi (*e*)	45′	6′ 7″	5′ 0″ × 1′ 6″ (forward)	16′ 0″ × 2′ 9″ (biplane)	4′ 6″ × 7′ 9″ (vertical 4′ 6″ × 7′ 9″ (horizontal)	29′ 6″
Short (new type)	Bi (*f*)	32′	5′ 9″	5′ 8″ × 1′ 6″ (forward)	10′ 0″ × 2′ 0″ (biplane)	8′ 0″ × 3′ 6″ (horizontal) 2′ 0″ × 5′ 0″ (vertical	30′
Sommer	Bi (*g*)	34′	6′ 9″	2′ 3″ × 2′ 0″ (twin)	13′ 9″ × 3′ 3″	10′ 0″ × 6′ 9″ (monoplane)	39′ 9″
Spencer-Stirling	Mono	34′	6′ 0″	2′ 10″ × 2′ 0″	3′ 6″ × 2′ 9″ (one each end of tail)	7′ 0″ × 2′ 9″	27′
Star	Mono	42′	8′ tapering to 6′	10 sq. ft. and 10 sq. ft. (of irregular shape)		30 sq. ft. as empennage	32′
Twining	Bi (*h*)	28′	4′ 6″	2′ 2″ × 1′ 4″ (twin forward)	10′ 0″ × 2′ 6″ (monoplane)	None	14′ 10″
Zodiac	Bi (*a*)	33′ 3″	6′ 6″	4′ 6″ × 3′ 3″	13′ 0″ × 2′ 6″	7′ 6″ × 6′ 6″ (biplane)	39′ 9″

Note.—T denotes propeller in front. P denotes propeller aft. 2T or

Surface.	Weight.	H.P.	Propeller diameter.	Propeller pitch.	R.P.M.	lb. H.P.	lb. sq. ft.	Remarks.
sq. ft.	lb.							
190	480	40–50	(T) 6′ 3″	2′ 3″	1500	9	2·5	—
201	450	30	(T) 6′ 10″	2′ 10″	1350	—	—	—
320	675	60	(T) 8′ 6″	4′ 8″	850	15	2	—
220	380	35–45	(T) 6′ 3″	4′ 6″	1200	11·2	1·7	—
170	500	35	(T) 8′ 0″	3′ 0″	1200	14	3	—
320 or 380	400	35	(T) 8′ 0″	3′ 0″	1200	11	1·2	—
590	885	30	(2P) 8′ 6″	11′ 9″	375	29·5	—	?
580	1200	60	(2P) 9′ 0″	12′ 0″	410	20	2	—
400	650	30	(P) 7′ 6″	7′ 6″	1200	22	1·6	—
526	700	50	(P) 8′ 4″	not known	900	14	1·3	—
210	650	70	(2T) 6′ 6″	10′ 0″	600	9·5	3	—
290	750	40	(T) 6′ 6″	3′ 9″	1400	19	2·5	—
277	440	20	(P) 6′ 3″	4′ 3″	1000	22	1·6	—
525	1100	50–60	(P) 8′ 0″	—	1200	18·3	2	—

2P means two propellers. The last three columns have been added.

Farman machines have taken two men weighing together over 300 lb. and 100 lb. of fuel and oil.

This figure of merit, weight per square foot should be taken with the greatest weight the machine will carry.

Pounds per horse-power is another figure of merit which cannot well be arrived at from these figures, but this column shows that some makers use much larger engines for the same weight of machine, the smaller machines having the greater horse-power per pound. A Demoiselle puts on 7 lb. per horse-power, a big Farman 26 lb. per horse-power.

When any useful purpose is to be contemplated for aeroplane machines, the weight carried per horse-power will be an important factor (horse-power per ton mile).

In the diagrams will be seen the various combinations, of main planes, tails, and rudders and elevators, and propellers. Given these five elements, and a sixth, the lateral balancers, an immense number of variations in the combination is possible, and by trying every conceivable variation perhaps the best one can be at last decided upon.

The machine shown in Fig. 37 is of elabo-

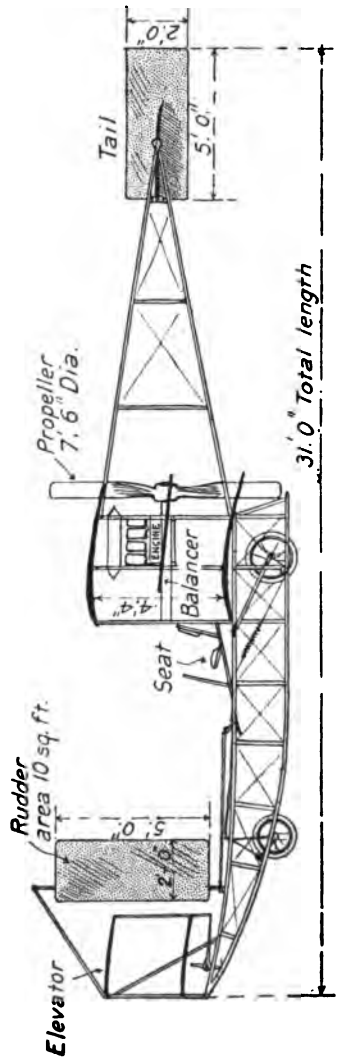

Fig. 37.—Biplane design, fore and aft planes.

rate but good design and of recent development.

What will be the ultimate design it is difficult to guess at present; only the results of continuous trials will eliminate the defective designs.

CHAPTER VII

THE PROPELLER

IN aeroplane machines a propeller is necessary. In order that an aeroplane machine can resist the pull of the earth, it must have a forward velocity of a certain minimum value.

If its velocity falls below the minimum it cannot remain up in the air. This is an inherent defect in the aeroplane machine.

The whole of the energy expended in keeping up the forward speed of the machine and in supporting its weight against gravity must come through the propeller from the engine.

The only propeller which has given any satisfactory results is the screw propeller. As the machine is submerged, a paddle-wheel is useless. Jet propulsion is also impracticable, for the size of the jets necessary to discharge the large weight of air required per second is beyond practical bounds.

From the theory of the screw propeller the

thrust is proportional to $T = \frac{wv}{g}$, where w is the weight of air driven astern by the propeller and v its velocity.

A screw working in a solid nut advances the length of the pitch P every revolution R, hence its advance = PR, but in a fluid it thrusts the yielding nut astern; the nut slips. If the screw is 12 ft. pitch and its advance only 9 ft. per revolution, then the slip is—

$$v = 12 - 9 = 3 \text{ ft. per revolution,}$$

and the slip per cent. is—

$$= v\,\% = \frac{12 - 9}{12} = 0{\cdot}25 \times 100 = 25\,\%.$$

Hence if P = pitch in feet and S = velocity of advance in feet per revolution, then—

$$\text{slip}\ \% = \frac{P - S}{P} \times 100.$$

If the revolutions per second is multiplied by the slip in feet we get the velocity v of the water slipped astern.

In the above case the slip was 3 ft. in each revolution. If the revolutions were 12 per second we get $v = 3 \times 12 = 36$ ft. per second.

W, the weight of air thrown astern by the screw, is, when the machine is in flight at forward speed S, equal to the area of the stream multiplied by S + V and the weight of one cubic foot of air = 0·08.

$$W = A \times 0{\cdot}08 \times (v + S),$$

$$\text{and } T = \frac{A \times 0{\cdot}08 \times (v + S)\, v}{32}.$$

But A is not equal to the disc area of the screw and V varies in the different parts of the area, so that a constant K has to be used to find the true area and thrust. This constant is found by experiment.

Thus a two-bladed propeller 6 ft. diameter, pitch 3·6 ft. at 1450 revolutions, or 24·2 revolutions per second, advancing at 60 ft. per second developed 150 lb. thrust.

Taking A as the disc area of the disc described by the blades = 28 ft. we get—

$$T = \frac{28 \times 0{\cdot}08 \times (v + S)\, v}{32};$$

$$v + S = PR = 3{\cdot}6 \times 24{\cdot}2 = 87;$$

$$v = v + S - S;$$

$$S = 60 \therefore v = 87 - 60 = 27 \text{ ft. per second};$$

$$T = \frac{28 \times 0{\cdot}08\,(27 + 60)\,27}{32} = 165 \text{ lb.}$$

By experiment the screw at this slip and speeds gave 150 lb. thrust.

K therefore would in this case equal $\frac{150}{165} = {\cdot}91$.

And for all similar propellers running at the same slip the thrust would be =

$$T = \frac{0{\cdot}91 \times AD\,(v + S)\, v}{32}.$$

By "similar" is meant propellers of the same proportions throughout, but on different scales.

Another formulæ for the thrust also employs a constant K for similar propellers, found by experiment. It is $T = \frac{K \times S^2 \times D^2}{1000}$ for screws in air, K for a 6 ft. propeller with a pitch of 3·6 ft., with S = 60, and a certain ratio of blade area to disc area gave K = 1·16;

$$\text{hence } T = \frac{1{\cdot}16 \times 60^2 \times 6^2}{1000} = 150.$$

It might have been thought that the thrust of a four-bladed screw would be twice that of a two-bladed one, and the thrust of a three-bladed screw would be 1·5 times that of a two-bladed one. It is found, however, that they are as 1, 1·33, and 1·55.

This, however, does not mean less efficiency; for although the four blades give 1·55 times the thrust instead of 2 times, the power they take is also only 1·55 times that of the two blades.

Hence two two-bladed propellers give 30 per cent. more thrust than one four-bladed having the same diameter and blade area, but the two two-bladed propellers will take 30 per cent. more power.

If we know the brake-horse-power in a propeller and the speed S of the machine ahead, then

the thrust equals $T = \frac{\text{B.H.P.} \times 550}{S}$. Hence, no propeller can possibly give more than a certain thrust per horse-power at any given speed ahead; for one horse-power the thrust at 60 ft. per second is $T = \frac{1 \times 550}{60} = 9$ lb. nearly; at 30 ft. per second the thrust could not exceed 19 lb. per horse-power.

The higher the speed the smaller the thrust per horse-power, hence when great claims are made for new propellers it is well to get a declaration of the forward speed at which the results are obtained.

The diameter of a propeller should be as large as can with safety and convenience be used on the machine.

Two moderate-speed propellers are better than one high-speed one.

The higher the speed of the engine the less its weight will be per horse-power. And it sometimes happens that the best speed of the engine does not correspond to the best speed of the propeller.

For both these reasons gearing between the propeller and engine offers decided advantages.

Good spur wheel or chain gearing will give an efficiency of more than 95 per cent. in transmis-

sion, and by its use we can employ any propeller at any speed we choose.

Here, again, it will be observed that there is a field for study with a view to improvements in applying the propeller. A good, well-designed propeller may be applied inefficiently, and two propellers may be better than one.

Under the same conditions of speed and thrust a four-bladed propeller took 22·4 horse-power while a two-bladed one took 25·3 horse-power, but the four-bladed one had twice the weight and cost more than double. And the question was whether to sacrifice weight at the expense of power, or *vice-versâ.* Gearing adds weight, but saves power, and in considering its adoption a balance must be struck between the two sides of the account.

The propeller is, of course, one of the most important elements of any flying machine. Fortunately the same laws and effects apply equally to propellers working in air and in water, and we have half a century of experience with propellers in water to draw upon.

The design and construction of propellers is a special line of work in itself and cannot be fully followed up in this work. Those who desire to take up propeller designing will find it very fully treated in many standard works.

Propellers of wood or aluminium, which would not be at all durable in water, are quite suitable for air. Wooden propellers have become quite common; they are made out of a slab which has been built up of layers of hard woods, such as walnut, the blades being carved out to a gauge, the favourite propeller being a two-bladed helical propeller as shown in Fig. 38.

Sir Hiram Maxim, who made many experiments with air propellers, prefers a blade wide at

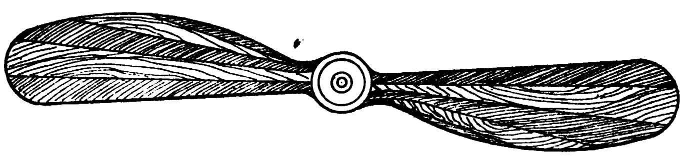

FIG. 38.—Aeroplane propeller.

the tips, with the sides almost radial, as shown in Fig. 39.

Others prefer what has been called a "malt shovel" propeller-blade as shown in Fig. 40; here the blade is at the extremity of a spoke, four of them being often used as in Fig. 33.

The best propellers under the best of conditions cannot give a higher efficiency than 70 per cent.; any attempt to get above that efficiency ends in the necessity for very large diameter of propeller at slow speed. It is very doubtful if any of the

small high-speed propellers on aeroplanes exceed 50 per cent. efficiency.

Referring to the list of machines and their particulars, pp. 90–93, we find, for instance, a propeller on the Bleriot running at 1200 revolutions

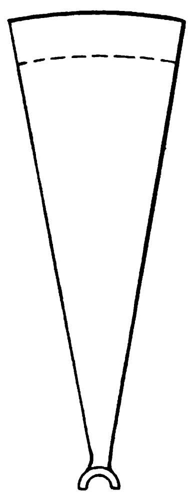

FIG. 39.—Propeller blade.

per minute with a pitch of 3 ft., that is, a propeller velocity $= 20 \times 3 = 60$ ft. per second = P.R.

If 3 ft. is the correct pitch then this machine would have no slip at an ahead speed of about forty miles per hour, and therefore no thrust.

There must be slip to get thrust.

The efficiency, if the speed of the aeroplane

ahead was 40 ft. per second, in which case the slip v would be 20 ft. per second, would be—

$$E = \frac{S}{S + \frac{V}{2}} = \frac{40}{40 + \frac{20}{2}} = \frac{40}{50} = 0{\cdot}8 = 80 \text{ per cent.}$$

FIG. 40.—Propeller blades.

But besides the slip there is a loss due to the propeller whirling the air round, and to friction, the amount of which depends upon good design

and workmanship, so that the efficiency might in this case be about 60 per cent. at the very utmost, and probably less.

The case of a large slow-speed machine propeller is that given as Short-Wright, a Wright Bros.' machine made by Short Bros.; revolutions per second = 6·25, pitch 11·75 ft. = 73·4 ft. per second = P.R. If this machine made 58 ft. per second the slip would be about 15 ft., hence efficiency would be, say—

$$\frac{58}{58 + \frac{15}{2}} = \frac{58}{65 \cdot 5} = 88 \text{ per cent.}$$

The diameter of this propeller is only 8·5 ft., so that it may very much be doubted if with such a small slip an adequate thrust would be obtained at the high speed ahead.

The horse-power, which may be presumed to be brake-horse-power, is stated to be 30; the maximum thrust this horse-power could possibly give would be at 58 ft. per second ahead speed—

$$T = \frac{0 \cdot 6 \times 30 \times 550}{58} = 170 \text{ lb.}$$

taking its efficiency at 60 per cent. on the propeller.

CHAPTER VIII

THE HELICOPTÉRÉ

THIS name has been fixed upon that class of flying machine designed to be lifted by the reaction of a screw propeller direct.

The argument is, that a helical blade rotating and advancing is simply an aeroplane travelling in a helical path instead of in a straight line of flight.

That is true, so long as the screw or helical blades are advancing into the air at or below the velocity PR.

But when a helicoptéré is rising it does so slowly; hence the helical blades are not travelling against the air in a helical path, and when the helicoptéré comes to a height at which it is desired to remain, the propeller is not advancing at all.

The thrust of a fixed propeller or one moving forward slowly is very small.

A helical blade is therefore useless for the purpose, and if we discard the helical blade "helicoptéré" must be discarded also.

Rotary aeroplane blades are better, that is, blades simply curved so that their leading edge takes the air tangentially without acceleration, but the air is gradually accelerated as it passes through the propeller.

Some patent fan blowers for air are so designed. Naturally the fan which gives the largest discharge of air per horse-power would be the best propeller.

Among propellers which have been usefully applied and which are designed on these lines is the screw turbine propeller of Thorneycroft's invention.

This propeller should give a large thrust without advancing into the air, and as it has guide-blades to utilise the rotary motion given to the air it gives a high efficiency.

The real difficulty, however, with rotary aeroplanes is their large dimensions. Even if we use the screw turbine principles with guide-blades the vertical propeller must have an area of blade surface somewhat more than half that of an aeroplane surface for a similar lift.

The mere mechanical difficulty in carrying and driving huge rotating propellers is almost insurmountable, and introduces balancing and other problems of great obscurity.

Nevertheless it may by mechanical ingenuity be made a successful machine.

We can here only refer to the germ of the machine, as nothing of any practical use has hitherto been developed.

A disc of sheet metal about 6 in. in diameter is cut, as shown in Fig. 41, with six blades. The blades are simply bent to a curve like aeroplane blades. Mounted upon a common cotton spool they can be rapidly rotated by a string wound on

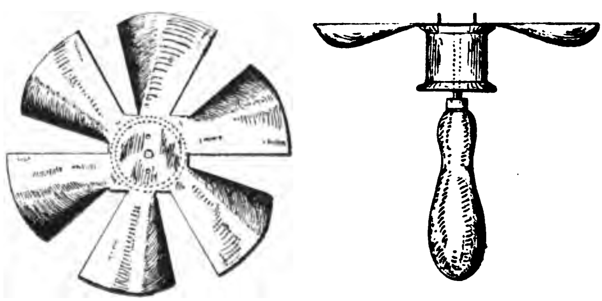

Fig. 41.—Lifting screw propeller.

the spool and pulled off quickly. This propeller will rise off the shaft to a considerable height.

But a moment's consideration will show that this is not what we want to know about a rotary plane machine. Like the screw propeller, it will work all right while advancing parallel to the axis of rotation. What we do want to know is how much weight will it sustain when not advancing, that is, when the machine has risen to

the desired height and is to be held at that height.

This can be found only by testing the thrust of the propeller with a given horse-power when not advancing.

The two cases are contrary; all tests of driving propellers must be made with the propeller advancing at a speed at or near that at which it is to propel.

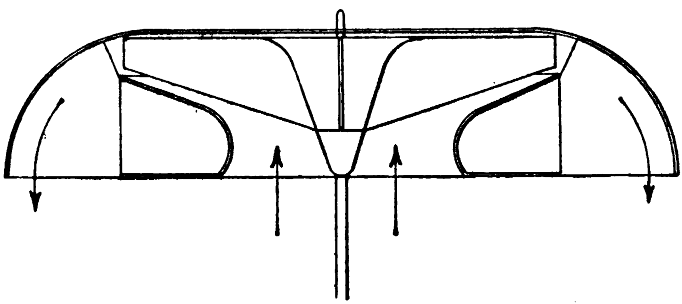

FIG. 42.—Turbine-aero.

And all tests of a lifting propeller must be made with the propeller fixed, not advancing.

A very considerable lift can be produced by a centrifugal fan, shown by a diagram in Figs. 42 and 43.

The casing is made so that the air is drawn in on the under side. Whatever vertical momentum the air may have is destroyed in being deflected from the vertical to the horizontal at the inlet of

the fan and the momentum becomes upward lift. The air is then accelerated by the fan and again deflected downwards, again giving an upward reaction.

The name "turbine-aero" has been given to this machine because it is based on turbine principles.

One of the simplest turbines, which happens

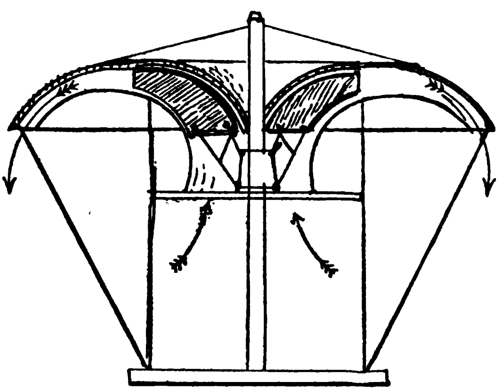

FIG. 43.—Turbine-aero.

also to be one of the most efficient, is that known as the Pelton wheel. The principles of this can be readily applied to a turbine-aero.

One bucket is shown at Fig. 43A in two views. There is a mid-rib in the bucket; the jet thrown against this rib divides into two streams, which are turned completely back in direction of motion.

The pressure P exerted by the jet against the bucket when the bucket is fixed, and when—

D = weight of the fluid per cubic foot;
A = sectional area of jet in square feet;
V = velocity of jet in feet per second;

$$P = \frac{(D.\,A.\,V.)\ V \times 2}{g}.$$

The expression D. A. V. gives W the weight of water delivered by the jet per second, so that

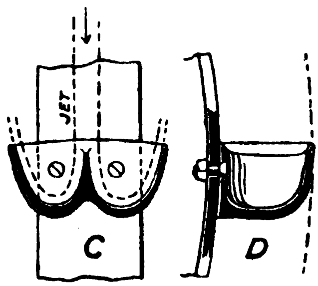

FIG. 43A.

$P = \dfrac{WV \times 2}{g}$, or generally $P = \dfrac{2 \times D.\,A.\,V.^2}{g}$ when the bucket is at rest or moving very slowly.

If the bucket moves at speed V_1 in the direction of the jet the quantity of water passing is still = D. A. V., but V_1, being the speed of the bucket moving away from the jet, the actual speed with which the jet now strikes the bucket = V_2, and $V_2 = V - V_1$; hence—

$$P = \frac{2 \times D.\,A.\,V.\,(V - V_1)}{g} \text{ or } P = \frac{2 \times W\,V_2}{g}.$$

The jet is twice deflected through an angle of 90 degrees; hence the multiplier 2.

If, now, we make an umbrella-shaped affair of light material, with a cone rising in the centre to a point, as in Fig. 42, and arrange to deliver a jet of air on the point of the cone, so that the point is concentric with the jet, the air will be deflected twice, and we will get a lift equal to $\frac{2\,\text{D.A.V.}^2}{g}$.

And with a jet of one square foot area A and an air velocity of 64 ft. per second and with D = 0·08 we would get very nearly a lift equal to $\frac{2 \times 0{\cdot}08 \times 1 \times 64 \times 64}{32} = 20\frac{1}{2}$ lb.

W here = 0·08 × 1 × 64 = 5·12 lb. of air per second. V = 64.

The horse-power required theoretically to produce this jet $= \frac{\text{W V}^2}{2\,g \times 550} = \frac{5{\cdot}12 \times 64 \times 64}{64 \times 550}$ = 0·6 horse-power nearly.

This is a lift equal to 33 lb. per horse-power.

Probably, however, the efficiency would not exceed 0·5, so that practically the lift would be 33 × 0·5 = 16·5 lb. per horse-power; hence a machine to lift 1000 lb. on these data would require $\frac{1000}{16{\cdot}5} = 60$ horse-power.

If a larger area of jet were used and a smaller velocity of jet the same total lift could be obtained with less horse-power, for the lift increases directly as w and as the square of v.

So far, then, this investigation shows that the theory is correct, and that it is a feasible plan.

But after investigating a flying machine proposition to ascertain its lift per horse-power, there remains to be ascertained the probable dimensions, and this is often the crux of the proposition. It is so in the case of the helicoptéré, for when we come to calculate a screw propeller, or even several screw propellers, on the one machine capable of sustaining the weight, their size is beyond the limits of practicability.

In the case just calculated we found that with a jet one foot area with a jet velocity of 64 ft. per second the lift was 20·5 lb.

Keeping to this jet velocity the lift will be directly as the area of the jet, which at 20 lb. lift per square foot of jet would require a jet of $\frac{800}{20}$ = 40 square ft., for a machine total weight of 800 lb. to be lifted, a jet of about 7 ft. diameter.

That does not seem impracticable or very formidable, especially as we might have two or four jets of half or fourth the area. With four jets each 10 square ft. area, their diameter will be

only 3 ft. 7 in. each. Thus step No. 2 in the investigation is completed.

The next step in the investigation into any new proposition for a flying machine is to ascertain how the principal elements are to be made and brought together so as to meet the requirements. In this step it is not necessary to go into minor details, but the production of the jet and its arrangement, together with the umbrella, and the application of the engine-power, must be clearly indicated in some practicable arrangement.

And this is where many would-be inventors fail. They conceive an idea, like that shown in Figs. 41 or 42, a mere skeleton of a proposition, and rest there, with the idea that they have made an invention, but they have not made an invention of any utility until they have shown exactly how the machine should be completed for practical work. Given the skeleton of the machine different minds would complete it in different ways.

Here we are considering only the principles of the turbine-aero. A possible machine in a diagrammatic sketch, showing the principal elements, is shown in Fig. 43. A centrifugal fan driven by the engine is to set the air in motion with the designed velocity. The air enters the stationary mouthpiece A (Fig. 43) with the full velocity and is deflected by the central cone, thus producing

a lift. The air then passes through the fan, where it receives its momentum, and is deflected again through an angle of 90°.

The area of the inlet at A and the annular outlet at B B are equal. Experiments with models are not, as a rule, very satisfactory, but tests on models bear out the theory of this type of machine. It presents some difficult mechanical

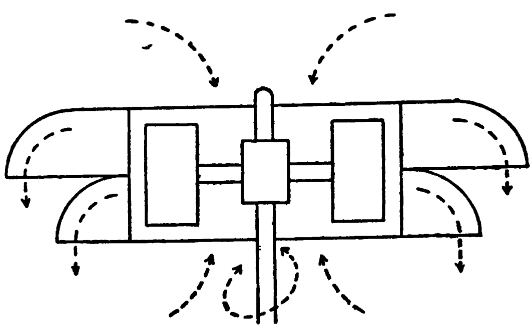

FIG. 44.—Turbine-aero.

construction problems. These, however, may be solved when the theory here given is clearly understood, and the calculations can be made as herein shown.

A machine of this type has been patented and exhibited at a show. The construction may be shown by a diagram (Fig. 44). The fan blower is horizontal, and it throws out a radial air current against the umbrella-shaped deflectors,

where it is turned once through 90°. Hence the lift would be only half that of a machine according to Fig. 43, where the current of air is turned through two angles of 90°.

The problems of constructing a machine to float in the air independent of forward motion and of a gas bag has not been solved even partially; perhaps these notes and sketches may put some minds to act upon the quest for such a machine. To the writer it seems a possible solution may be arrived at on these lines.

CHAPTER IX

THE WING PROPELLER

THE wing is Nature's propeller; its beautiful adaptation in bats, birds, and insects is before us continually. Its vibratory motion is difficult to imitate mechanically, but, what is more serious, in any attempts to apply mechanical wings the weight of materials at the disposal of the mechanic is far beyond the weight of the materials employed in Nature. The strength of the bird's wing compared with its weight is a marvellous illustration of Nature's adaptation of a means to an end.

A flapping motion given to a heavy body throws enormous strains upon the mechanism, at the reversals, due to inertia.

The screw propeller, see Fig. 38, is a pair of wings, but their action is continuously in one direction, without reversal; but flight with a screw propeller is only possible in conjunction with a long inclined plane surface, whereas the wing serves both purposes—propelling and supporting,

and also steering and balancing, all performed by the one simple apparatus.

Several of the early experimenters tried mechanical wings, Mr. Hugh Bastin and Mr. Lawrence Hargreaves among others. Both of these experimenters made machines which actually did fly as models. Their experiments, however, were limited by the want of a proper prime mover.

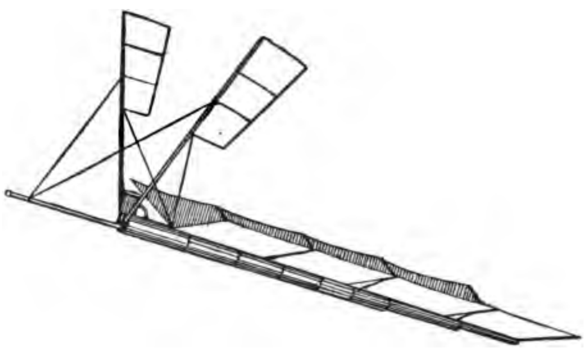

FIG. 45.—Hargreaves' flying machine.

The petrol engine at the date of their experiments did not exist as a small-weight motor, and only the heavy steam engine and boiler were available.

Hargreaves' wings are shown in Fig. 45. They consisted of two flaps of springy sheet material mounted upon two vibrating poles. As they vibrated the resistance of the air bent them into a shape not unlike two aeroplanes, the reaction of the bending force driving them forward.

Bastin's machine was modelled as shown in Fig. 46, the wings being vibrated on trunnions by mechanism within the body.

No large-winged machines working with the flapping wing have been a success hitherto.

The ultimate safety and reliability of the flying machine heavier than air is that of the engine. No doubt a glide to earth can be made when the

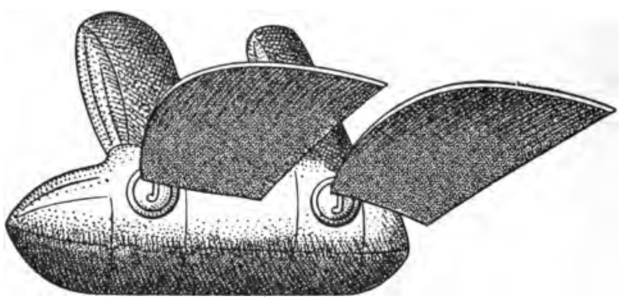

FIG. 46.—Bastin's winged flying machine.

power fails and a safe landing sometimes made, but a safe landing is not always to be relied upon, and it may be made in a position where a rising cannot be again made.

In any case a failure of the power puts an end to the journey in most cases, and may always be looked upon as a serious matter.

In no other case of locomotion is the failure of the power of such great importance. The engines of a ship may fail, but she does not sink; the

engines of a motor car may stop, but there is no danger of a smash therefrom; a railway locomotive may fail—the train simply stops till another locomotive takes it on.

One of the very first requisites is, therefore, a thoroughly reliable engine. For the short spins which aeroplanes make over chosen ground the present engines are fairly reliable. The great flight from London to Manchester was done in a short time in two laps. Just how long the present type of engines will run continuously on an actual flight is not known. Tests of engines on a fixed bed-plate are not of much value in this respect, for an engine in actual flight is working under different conditions.

CHAPTER X

THE ENGINE

THE engine is a speciality into which we cannot here enter deeply. The success of the aeroplane has brought out a special type of engine of great power per lb. weight—the rotary cylinder engine, in which the crank is a fixture and the cylinders and pistons revolve around its shaft centre.

The chief advantage of this construction is that the cylinders flying round are thoroughly cooled by contact with the air, so that all the weight of water cooling is saved. The cylinders also act as a flywheel and greatly steady the motion. As many as seven cylinders are used on this engine, so that the turning torque is fairly even. The reason for the use of seven-cylinders instead of an even number is given in the following description from the 'Aero,' May 3rd, 1910, referring to diagrams 41 and 42:

"Fig. 47 represents a six-cylinder rotary piston engine, the radial lines indicating the cylinders.

It is possible to fire the charges in two ways, firstly, in rotation, 1, 2, 3, 4, 5, 6, thus having six impulses in one revolution and none in the next; or alternately, 1, 3, 5, 2, 4, 6, in which case the engine will have turned through an equal number of degrees between impulses 1 and 3, and 3 and 5, but a greater number between 5 and 2, even again

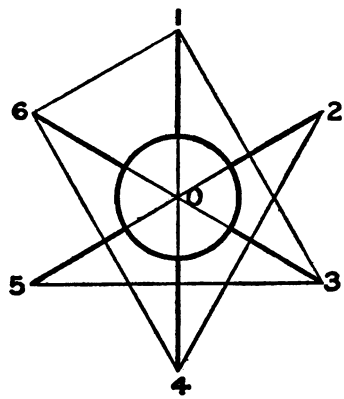

FIG. 47.

between 2 and 4, 4 and 6, and a less number between 6 and 1, as will be clearly seen on reference to the diagram.

"Turning to Fig. 48, which represents a seven-cylinder engine, if the cylinders fire alternately it is obvious that the engine turns through an equal number of degrees between each impulse, thus, 1, 3, 5, 7, 2, 4, 6, 1, 3, etc.

"Thus supposing the engine to be revolving, the

explosion takes place as each alternate cylinder passes, for instance, the point 1 on the diagram, and the ignition is actually operated in this way by a single contact.

"A few particulars of the Gnome engine will not come amiss, since it has proved on many occasions that the rotary piston engine has come to stay. The bore is 4·3 in., the stroke 4·7 in., and at 1000

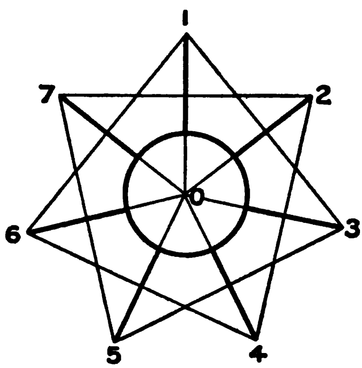

FIG. 48.

revolutions per minute the engine develops 50 b.h.p., the complete weight being about 165 to 170 lb.

"Gas is admitted through the hollow crank-shaft to the crank-case, whence it reaches the cylinders through automatic valves in the pistons, and the lubricant enters similarly.

"The connecting rods are interesting (see Fig.

49) : one rod is formed at the big end into a cage for the large ball race on the crank pin, and the outer rings of the cage carry the plain bearings

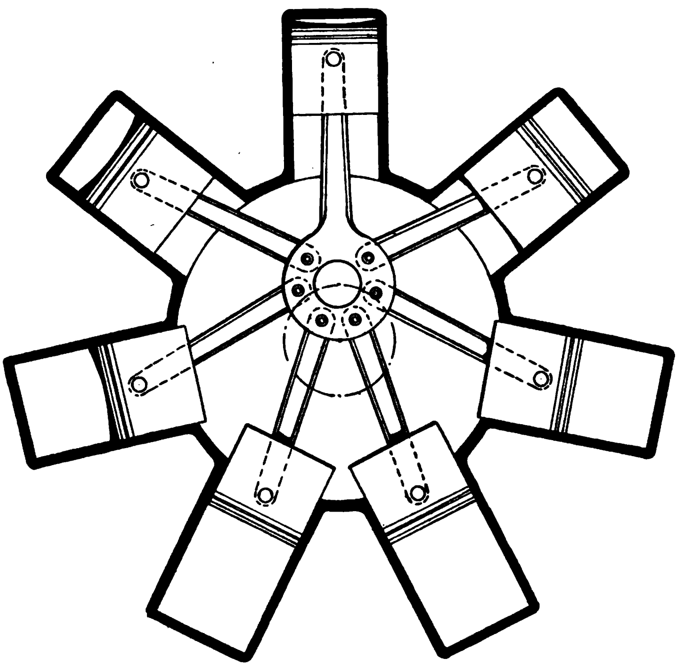

Fig. 49.

for the other six connecting rods. The gudgeon pins are mounted in separate pieces, which are screwed into the piston heads, these pieces also carrying the automatic inlet valves. Practically the whole engine is made of steel, and all bearings

run on balls. The cylinders are turned out of solid steel bar, being eventually only 1·2 millimetres thick. It is a little consoling to know that this machining operation, which used to take sixteen hours for each cylinder, is now performed more accurately in two and three quarter hours.

"The beautifully steady running of the engine is largely due to the fact that there are literally no reciprocating parts in the absolute sense, the apparent reciprocation between pistons and cylinders being solely a relative reciprocation, since both travel in circular paths, that of the pistons, however, being eccentric by one half of the stroke length to that of the cylinder.

"As in the case of the single ignition point, a single cam lifts each exhaust valve in turn as it passes a fixed point, the inlet valves in the piston heads being automatic."

It has been calculated that, at full speed, these engines absorb 7 to 9 h.p. simply in displacing air as they whirl round, and advocates of water-cooling adduce this as evidence that water-cooling is at least equally economical. It would be interesting to see some tests in this direction carried out.

Meantime the Gnome has proved itself highly efficient by the victories it has won and the records it holds.

The engine overhangs in front of the machine and the propeller is attached directly to it.

For aeroplanes as we presently know them probably this engine represents the best type. However, good results have been obtained with ordinary motor-car engines built of specially light weight.

Future developments may improve the control of the aeroplane so that it may be more powerful and positive, and not so much dependent upon the skill of the pilot. And machines of much greater power and carrying capacity will be built and flown. With these larger machines more instructive experience can be looked for.

The engine in future machines will probably be called upon to do more than propelling.

Engine power instead of manual power must sooner or later be employed to controlling the machine in flight. And that power may be taken from the propelling engine, thus saving the complications of separate engines.

Machines in future must be of larger dimensions and powers, so that the type of engine at present found superior may likely give place to others of larger power, driving larger screws at lower speeds, and very probably by chain gearing. A well-designed, and balanced, two-stroke engine seems to meet the case best with water cooling.

It would be better to follow the example of the Gnome engine, and to design an engine specially for flying machines than to attempt the adaptation of the motor-car engine.

CHAPTER XI

THE AEROPLANE'S FUTURE

LIKE every mechanical invention, the aeroplane machine of the future will be the result of a course of evolution, partly from experimental results and by scientific discoveries.

The "art of aviation," or aerial navigation, has received an astonishing amount of attention and solid encouragement in the form of about £50,000 to £60,000 in cash prizes offered to drivers of aeroplane machines, and yet the art of aerial navigation on an aeroplane is not a difficult one to acquire. It can be learnt, like riding a bicycle, in about a dozen lessons, by any person in fairly good health and mental balance. There is great danger, of course, as the many accidents to capable drivers have proved, but these are due to the very primitive and defective engineering of the design and construction of the machine.

It is not the "art" of aerial navigation which requires encouragement at all; in fact, in the

present stage of the development of the machine, some discouragement seems to become necessary.

The excessive encouragement offered to aeroplane drivers by large cash prizes has led up to the many foolhardy flights which have ended disastrously.

The urgent need at the present stage is the improvement of the machine. There is enormous scope for improvements, and many radical changes must be made before it can be seriously considered as a useful machine for any purpose commercially, naval, or military. The feats which have been performed upon the aeroplane prove only that flight is possible with them and that they are controllable within limits, and the results as a whole to date show that much remains to be done by the engineer to bring the machine within the range of practical utility.

Blondin, the rope-walker, performed feats on a rope used as a bridge across Niagara River, which proved that a single rope could be successfully used as a bridge. He walked over, carried a passenger over, wheeled a barrow over, and performed other feats upon it, but all that did not make a rope a successful bridge for common traffic or for military purposes; similarly many feats can be performed by a skilful performer on the aeroplane.

The young engineer in other branches of engineering often complains that everything has already been brought to such a high degree of perfection that there is no room for his ingenuity to distinguish himself by making discoveries or improvements. This cannot be said of aeronautical engineering. Here everything is in a primitive stage; to the skilled engineer of ability and with inventive talent it opens up a wide field for activity. It may not offer much of a money prize for the labour expended, not to speak of cash expended, but it offers something of value to him who has the ability to make substantial improvements.

The defects of the present-day machines can be summed up in a few words. All through they are deficient in what engineers term "the margin of safety." In all mechanical structures a high factor of safety is necessary.

Necessarily a flying machine must be of the smallest possible weight compatible with sufficient strength. But the tendency is to reduce the weight until the strength is insufficient.

The margin of safety in this respect is small, and smaller, the smaller the machine.

Probably to make a flying machine with a factor of structural safety as high as that for a bridge or for a sailing yacht would result in a

weight too great to be lifted at all. So long as that is so we must risk a machine with a factor of safety less than what would be accepted for other machines structurally.

Then there is the factor of safety for stability. In a ship or a yacht, stability can be given a high factor of safety by designing the meta-centre height high enough above the centre of gravity; and be certain of its automatic action, and the buoyancy ensures longitudinal stability. Stability, longitudinal and lateral, presents some difficult problems in aeroplanes. There is no buoyancy, and, therefore, properly speaking, can be no metacentre.

In place of buoyancy to float the machine we have the machine driven at a high velocity through the fluid, in which it is floated by the reaction of the fluid it deflects or accelerates in a downward direction.

And the whole weight is hung upon the deflectors, *i. e.* the planes. Neglecting other considerations stability could be given by placing the planes above the centre of gravity. And to some extent this is done in more recent machines, and by further improvements it may be still further advanced until a fair amount of inherent stability is thereby given to the machine.

At present, however, the factor of stability

depends upon the manipulation of auxiliary planes or wing-warping, or both, by the driver, and this manipulation it is which requires to be learnt by the would-be driver of an aeroplane.

Like the rope-walker, the flying machine at present is in a constant state of unstable equilibrium, and, so long as it is so, accidents and failures will be the rule. Automatic balancing by some means or other must be found, and no doubt will be found, to make the machine reasonably safe in that respect of stability.

Then there is the third factor of safety in the motive power. Unlike all other locomotive machines, the aeroplane must keep moving at a high rate of speed in order to keep afloat. The slowing down of the motor or its stoppage for more than a few seconds means coming down. This has happened often. Fortunately in some cases the machine has come down under control as a glider; in other cases it has come down out of all control. And in any case it may come down in some very awkward place.

The importance of a very high factor of safety in the motor is therefore very apparent.

In a ship, a motor-car, or a locomotive on a railway, the factor of motor safety is, of course, important, but it is a thousand times more important in an aeroplane machine.

Then there are the problems of starting up and alighting. These are not so important, but still there is a field here for much improvement also.

Possibly the nearest approach to practical experience in structural construction akin to that required in aeroplanes is in racing yacht building, in which much consideration has been given to small weight combined with great strength, and the materials are similar.

The rigging of a sailing yacht is exposed to the same elements and similar stresses and strains as the aeroplane; the sails are aeroplanes. The aeroplane designers might with advantage study the rigging of a large yacht, the sails of which in some instances develop over 700 horsepower (that is to say, propel the vessel at a speed which would take that horse-power to develop it).

It is safe enough to prophesy that the present system of construction will be departed from very widely in future aeroplanes. It will not be difficult to design the machine with greater strength proportional to weight than those to be seen at present. In some recent machines designed by engineers who evidently have some notions regarding the elements of structures, this tendency towards a ship rigging design is evident already.

Another point on which suggestion might be

made is that of auxiliary planes on machines. Theoretically, the fewer auxiliary planes on any machine, the better. At present auxiliary planes, "ailerons," are used for lateral balancing, for steering, and for elevating; the steering planes are vertical, but a vertical plane in a flying machine will always be a source of trouble in a wind. Properly, there should be no vertical planes.

Horizontal planes for elevating and balancing are not so much objectionable, but more than likely they also in time will be discarded in favour of a better system.

The three fundamental elements of the aeroplane which will always remain, whatever else goes, are the prime mover, the propeller, and the sustaining planes.

At present there is only one prime mover competent for the work—the petrol motor—of which there are several varieties to choose from.

The propeller which has proved best is the ordinary screw-propeller, but made of wood. The only observation to be made on the results of flights hitherto made, on the engine and propeller question is, that there seems to be a considerable waste of power; but it is a question, this, which cannot very well be discussed, for the statements made as to engine power are not very reliable.

The planes, as has been shown, have been the subject of much speculation as to their proper form, and many fantastic sections have been proposed. Designed on the principles herein discussed they are highly efficient and are not likely to be much improved upon, except in the matter of structure.

A sketch (Fig. 50) of the original aeroplane of Prof. Langley's design is here given. It is

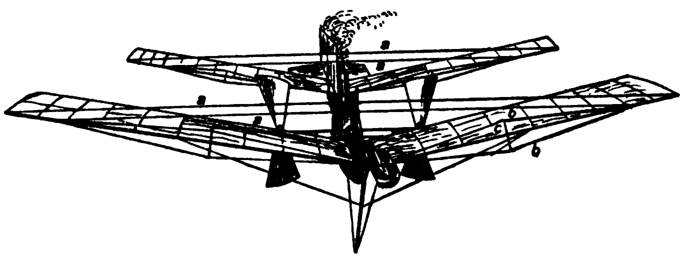

FIG. 50.—Professor Langley's aeroplane—the first power-driven flying machine.

of interest historically and scientifically. And, practically, the machines of to-day are to all intents and purposes similar to it in design.

The pioneers of the aeroplane machine were O. Chanute, Prof. Langley, and the Wright Brothers, Orville and Wilbur, of Dayton, U.S.A., so that it may be said to be of American origin. In France something was done in the way of pioneering by Mr. Santos Dumont, Mr. H. Farman, and the Voisin Brothers. In this country

the preference is to encourage prize-hunting and rather to discourage inventors, hence we have no pioneers in the aeroplane machine development.

Lillienthal in Germany did a great deal of work in aeroplane gliding, some of which gave valuable information for future guidance, and Loessl's investigations, mathematically and experimentally, have been of great value in problems of flight generally.

Whatever may be the developments practically, the "science" of the subject will make rapid strides in progress. And that will very much lessen the difficulties of the future inventors and improvers. The aforementioned early pioneers had no experience and little science to guide them; their results were all the more creditable. Again, in the matter of materials and appliances, the present and future improvers are better off when tackling a problem. The early pioneers could not find a suitable motor even—nothing but a steam-engine.

The improvement of the flying machine is the supreme problem of to-day. Among engineers how far it may be developed no man can say, but it is manifest that it can be carried to a much higher degree of perfection than the best machines yet produced.

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